ROBOTICS AND AUTOMATION

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Newsletter of the IEEE Council on Robotics and Automation

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From the Editor:

From our first issue to our second issue we have gone from not enough material to fill sixteen pages to too much. This significant increase in contributions is just one indication of the continuing growth of interest in advanced automation. In particular we are pleased to publish the results of a survey on robotics education conducted by Professor M. Eslami and funded by a grant from the IEEE Council on Robotics and Automation. We hope this will provide a springboard for discussion of robotics and automation curriculum on both the graduate and undergraduate level.

On a personal note, from September 1 through sometime next spring I will be on a leave of absence from North Carolina State University, working with DFVLR, the West German Air and Space Agency near Munich. We are very much looking forward to it.

Next year we will begin a quarterly publication schedule. Thanks to the wonders of electronic communication we expect to get the newsletter out on time. Contributions should be mailed to Communication Unlimited, Inc., 4605 Western Blvd., Raleigh, NC 27606. Telephone inquiries should be directed to Ms. Annette Beach at 919-851-1368. Auf Wiedersehen.

1988 IEEE INTERNATIONAL CONFERENCE ON

ROBOTICS AND AUTOMATION

April 25-29, 1988
Wyndham Franklin Plaza Hotel
Philadelphia, PA

Sponsored by the IEEE Council on Robotics and Automation

General Chairman: **T. Pavlidis,** SUNY at Stony Brook, NY
Program Chairman: **R.B. Kelley,** Rensselaer Polytechnic Inst.
Treasurer and Coordinator: **Harry Hayman**
Local Arrangements: **R.P. Paul,** University of Pennsylvania

ADVANCE ANNOUNCEMENT
and
CALL FOR PAPERS

Original basic and applied papers in all areas of robotics and automation are solicited. Specific topics include, but are not limited to the following:

- Applications in prosthetics, rehabilitation, handicap assistance.
- Automation and manufacturing systems.
- Control, dynamics, and manipulator design.
- Devices, architecture and expert systems.
- Electronics manufacture.
- Intelligent systems in automation.
- Mobility and navigation.
- Robot vision and inspection systems.
- Robotics in construction, underwater, and hostile environments.
- Sensors.
- Space applications.
- Systems architectures and programming.
- Systems design software and simulation.

The organizers encourage the submission of noncommercial papers from representatives of industry, universities, research institutions, and government.

PAPER SUBMISSION: Contact: **Robert B. Kelley**
ECSE Department
Rensselaer Polytechnic Institute
Troy, NY 12180-3590

All authors will be expected to assist in the review process by reviewing two papers for each paper submitted.

Authors will be notified of acceptance and furnished with an author's kit. Final papers in camera-ready form will be due January 15, 1988. Final papers received by the deadline will be included in the proceedings available at the conference.

The conference hosts tutorials on Monday, April 25, 1988 and a workshop and tours on Friday, April 29, 1988. Conference sessions will be held on Tuesday, April 26 to Thursday, April 28, 1988. Those with proposals for tutorials or the workshop should contact:

Alan Desrochers
ECSE Department
Rensselaer Polytechnic Institute
Troy, NY 12180-3590

For further information detach and send this coupon to:

1988 IEEE INTERNATIONAL CONFERENCE ON
ROBOTICS AND AUTOMATION
Conference

c/o Harry Hayman
738 Whitaker Terrace
Silver Spring, MD 20901
Telephone (301) 434-1990

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
IEEE

The President's Letter

Antal K. Bejczy
1987 President
IEEE Council on Robotics and Automation

The activities sponsored by the IEEE Council of Robotics and Automation have reached a level of maturity which motivated the Council to conduct a survey of the robotics and automation community to ascertain the level of interest in the formation of an IEEE Robotics and Automation Society. The survey of interest form was mailed in April, 1987, to about twelve thousand individuals; about nine thousand in the U.S.A. and three thousand in foreign countries. The names and addresses were drawn from attendance lists of the Council-sponsored IEEE International Conference on Robotics and Automation, from the subscribers' list of the Council-sponsored IEEE Journal of Robotics and Automation, and from IEEE member files. Closing date for the responses was the end of July, 1987. Within three months, about three thousand individuals responded to the survey, corresponding to about a 25% response rate. This response rate is quite acceptable for this type of survey. A detailed analysis of the responses will be presented in the next issue of this newsletter. Here, I am only summarizing the main results.

The main question posed by the survey was to ascertain whether there is a perceived need for an IEEE Robotics and Automation Society. For a brief summary of the survey results, the responses can be sorted in two groups according to the respondents' answer to the question: "Do you consider your professional work to be within the discipline of robotics and automation?" According to the answer to this question, about 50% of the respondents (nearly fifteen hundred individuals) belong to the robotics and automation professionals. Of these professionals an imposing 80% said "yes" for an IEEE Robotics and Automation Society with nearly 60% of all other respondents agreeing. Would they join this new Society? Again, over 85% of robotics and automation professionals said "yes" with over 40% of all other respondents indicating that they would join. If they joined, over 70% of the robotics and automation professionals would participate in local Society activities together with nearly 40% of all other respondents.

The strong response briefly summarized above speaks plainly for itself. The measures also suggest the presence of a strong segment of non-professional robotics and automation enthusiasts within the IEEE membership. Putting aside the issue of professional or non-professional interest, the survey found that nearly two thousand individuals would join a new IEEE Robotics and Automation Society.

The IEEE Council of Robotics and Automation, in close cooperation with the management of IEEE Headquarters, is now in the process of putting together an agenda based on the survey results. The survey results will also be presented at the next IEEE Technical Activities Board (TAB) meeting in late November, 1987. We hope that the future administrative and organizational steps taken by IEEE will help those individuals who today are inclined to join a new IEEE Robotics and Automation Society to do constructive work.

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Raleigh Conference Report

Y.C. Ho
1987 Chairman
Robotics and Automation Conference

Attendance figures for the 1987 Conference on Robotics & Automation indicate a substantial increase in international participation. This increase in size and diversity of foreign attendance at the Conference is most encouraging. Given the long lead time for planning we should perhaps be thinking in terms of a foreign site for the Conference in 1990 or beyond. Any volunteer groups?

The change this year to a "sandwich format" with

a Monday tutorial and a Friday workshop is a success. Although attendance at the Raleigh conference was 11% lower than attendance at San Francisco, workshop attendance was 25% higher than at the '86 conference, and tutorial attendance was nearly tripled. These figures underscore an obvious need for continuing education which the Council and the Conference is providing. Thanks to our Education Committee Chairman, Alan Desrochers.

The participation of the manufacturing automation segment of the field is still lagging behind. I personally believe that we should not place all our eggs in one basket and should cultivate a balanced growth on the automation side. More manufacturing papers, please, from all authors!

Even taking into consideration the locality difference between San Francisco and Raleigh and a deliberate attempt at limiting the size of the conference through paper selection, the '86 attendance figures may be showing evidence of a slowdown in the growth of the robotics field. While this is not necessarily a cause for alarm, we should watch carefully the corresponding figure for the Philadelphia site next year.

The financial and other successes of the conference are due in no small measure to the contributions (in money and in effort) of the North Carolina State University, the City of Raleigh, and the local arrangement team of Wes and Roz Snyder. My sincere gratitude to them.

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Robotics TC Report

The Technical Committee (TC) on Robotics of the Computer Society of the IEEE is composed of individual members of the Computer Society with special interest in robotics. The TC was formed in 1982 with Dr. John Jarvis as its first chairman. Dr. Wesley Snyder succeeded him in 1984 and served until 1986. Dr. Mohan Trivedi is the current chairman of the TC. The TC now has over 900 active members.

Scope: The scope of the Robotics TC includes robot control systems, robot programming languages, planning and spatial reasoning, interpretation of sensor signals, application of machine vision to robot control, and the interaction of robotics with CAD/CAM functions. The technical focus is directed more towards the control and machine perception aspects of the field than on manipulator mechanics and detailed applications.

Activities: The TC promotes the exchange of ideas by sponsoring technical workshops, special sessions, publication of a newsletter, and helping to develop standards. It also coordinates with other robotics activities in the field, and supplies guest editors, session organizers, tutorial instructors, and journal/proceedings paper reviewers. Many of the TC activities are performed in cooperation with the Robotics and Automation Council. The TC is represented by Profs. Eric Grimson and Wesley Snyder on the Robotics and Automation Council's Advisory Committee (ADCOM).

Specific activities already planned by the TC include cooperation with the International Society for Optical Engineering (SPIE) in organizing the *Applications of Artificial Intelligence Conference* in April '88 in Orlando. This conference will include several sessions on robotics related topics. Professors Azriel Rosenfeld and B. Chandrasekaran will deliver the keynote addresses. Plans are also underway to organize one or more workshops during the next year. Potential topics include robot vision systems, computer architectures for robotics and robotic programming languages.

Invitation: The Robotics TC invites persons with special interest in robotics to actively participate in its activities. If you are not currently a member of the TC you are invited to submit a membership application form. If you need additional information, please contact Mohan Trivedi (Ph: 615-974-5450; E-mail <trivedi@vms1.engr.utk.edu>; Dept. of Electrical and Computer Engineering, The University of Tennessee, Knoxville, TN 37996-2100)

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1988 Conference Program Plans Underway

The format of the 1988 Robotics & Automation will be designed to ensure that the Conference continues to be a "researchers' conference, where people working in the field can hear reports

on work in progress and learn what is going on in R&A research", says Dr. Robert Kelly of Rensselaer Polytechnic Institute, The program committee will finalize the format of the conference by mid-autumn.

According to Dr. Kelly, the conference proceedings, which have grown from one volume to three hefty tomes in 1986, will not continue to expand. The program committee is considering a combination of long and short papers, and a schedule consisting of no more than five parallel sessions. The resulting proceedings should be no more than two volumes, and will have a higher archival value than a larger proceedings.

"We would like the proceedings to provide a record of what was going on at the conference, and allow archival publications to appear in journals," Dr. Kelly said.

Dr. Kelly noted that since 1985 several journals in the area of Robotics and Automation have appeared, providing an outlet for archival publications which was formerly available only in the conference proceedings.

Another possibility under consideration is the inclusion of lead-off papers, particularly for invited sessions, which would provide a summary of the state of the art in a particular research area. Other authors in the session would not need to restate the introduction.

Finally, the committee is interested in encouraging the active participation of graduate students in the conference.

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Philips Prize Announced

North American Philips Laboratories will award a $1000.00 prize for the best single authored paper presented at the 1988 Robotics and Automation Conference by a graduate student or by a new Ph.D, based on his thesis work. Dr. Ernie Kent of the Robotics and Flexible Automation Deptartment of Philips Laboratories, announced the prize, which will be awarded at the conference banquet. The recipient will be determined by the conference program committee.

Dr. Kent stated that Philips is awarding the prize as an incentive to encourage students to participate in the conference, and to call their attention to the ongoing work in robotics at Philips Laboratories.

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R&A Council Finances

Richard Klafter
1987 Treasurer
IEEE Council on Robotics and Automation

The Council is currently in a sound financial position. As of April 30, we had a surplus of over $200,000. However, the decision to increase the number of issues and the total number of pages of the Journal plus the added cost of the new newsletter will consume some of this surplus.

The Board of the Council understands this and is taking the necessary steps to prevent this depletion of reserves from becoming the norm.

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Engineering Foundation's Engineering Research Initiation Grants for 1988-89

For the first time up to three grants of $20,000 each may be awarded on a competitive basis to IEEE members for proposed research projects in fields of mutual interest to the Founder Society and to the Engineering Foundation.

The IEEE , 345 E. 47th St., New York, NY 10017, will accept proposals received by November 15, 1987.

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Calendar

Annual IEEE Design Automation Workshop, January 13-15, 1988. Apache Junction, Arizona. Contact Walling Cyre, Control Data, HQM 173, Box 1249, Minneapolis, MN 55440. (612) 853-2692.

Applications of Artificial Intelligence, April 4-8, 1988. Peabody Orlando Hotel, Orlando, Florida.

BPRA 4th International Conference on Pattern Recognition, March 28- 30, 1988. Queens College, Cambridge, England. For information contact Dr. J. Kittler, Dept. Electronic and Electrical Engineering, University of Surrey, Guildford GU2 5XH, England.

IAPR 9th International Conference on Pattern Recognition, October 17- 20, 1988. Beijing, China. For information contact 9ICPR Secretariat, Chinese Association of Automation, P.O. Box 2728, Beijing, China.

19th International Symposium and Exposition on Robots. 1988. Sydney, Australia. The symposium will be held as part of Australia's bicentennial celebration. Papers presented will discuss the complex applications and implications of robot technology in modern society. The exposition will display robots at work in industry, the home, and educational institutions. Contact Dr. Michael Kassler, The Australian Robot Association, 9 Queens Ave., McMahons Pt., Sydney 2060, Australia. Tel: (02) 922-5026.

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Editorial Policy

We accept news items, surveys, letters, positions available, calendar items, book reviews, and reports on work in progress. Normally, technical contributions will not be reviewed. However, the editor reserves the right to solicit technical reviews and to edit any contributions for style, clarity, and brevity, and to reject any contribution which is inappropriate for this newsletter.

Universities may submit position available announcements, which will be published at no cost provided they do not exceed three column inches. We will also publish commercial advertisements, pricing information can be obtained by calling 919-851-1368.

A WORLDWIDE SURVEY OF ROBOTICS EDUCATION

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The University of Illinois at Chicago
Chicago, Illinois 60680-4348

ABSTRACT

Certain robotics educational activities of 65 higher - educational institutions in Austria, Canada, England, Finland, France, Greece, Italy, Japan and the United States of America are reviewed based on a questionnaire that was prepared and sent to these institutions by the author.

1. INTRODUCTION

In December of 1985 and during the 24th IEEE Control and Decision Conference, Dr. A.K. Bejczy of the Jet Propulsion Laboratory suggested to this author that it would be a worthwhile effort if *a factual data bank* of the types of activities now being undertaken in various universities, particularly in this country, can be developed. This information will help those institutions that plan to develop such programs and it will certainly provide a step toward standardization of this discipline and will enhance the potential of cooperation between various research laboratories and the universities. Therefore a questionnaire was prepared and sent to a number of institutions. In the following we present an updated version of what we could conclude from approximately 72 answers received to our questionnaire that was sent to about 155 individual faculty members, or electrical and a few mechanical engineering department offices around the world. Due to the fact that most responses were handwritten (except for a very few) and some very difficult to read, it is the author's sincere apology if certain names are misprinted or some proper titles are omitted. Certainly, a number of these participants may now have changed their affiliations. There are a number of other outstanding programs in robotics that are not listed below mainly because no response to our questionnaire was received from these institutions.

2. INSTITUTIONS

Approximately 155 letters were distributed among a variety of institutions and 72 answers from 65 different institutions were received. These responses are grouped into the following 68 entries with some institutions having more than one entry. The names of those who answered our questionnaire are given in italic. The remaining names are participants and/or collaborators in the corresponding robotics teaching and research activities of the given institution and were provided by the respondant.

Austria

[1] Technische Universitat Wien, Institute of Mechanik, *Prof. K. Desoyer.*

[2] Universitat Linz, Institute of Systemtechnik und Automatisierung, *Prof. P. Kopacek.*

Canada

[3] Carleton University, Dept. of Mechanical and Aeronautical Engineering, *Prof. J.Z. Sasiadek.*

[4] University of British Columbia, Dept. of Electrical Engineering (EE), *Prof. P.D. Lawrence,* Professors E. Bohn (EE), D. Cherchas (Mechanical) and F. Sessani (ME).

[5] University of Ottawa, Dept. of EE, *Prof. D.T. Gibbons,* Professors E. Petriu and H. Riaz.

[6] University of Regina, Faculty of Engineering, *Dr. D.G. Vandenberghe,* Professors K. Faggetter and J. Katzberg.

[7] University of Toronto, Dept. of ME, *Prof. A.A. Goldenberg,* Professors R.G. Fenton, B. Behabib, K.C. Smith and W.L. Cleghorn.

England

[8] Bristol Polytechnic, Dept. of Engineering, *Dr. J.J. Hill,* Dr. R.W. Cliffe, Dr. C. Earl, Dr. R.J. Stamp, Mr. T.M. Hill, Mr. J. Tannock and Mr. S. Andrews.

Finland

[9] Tampere University of Technology, Dept. of ME, *Prof. H. Koivo* and Prof. A. Peltowaa.

France

[10] Ecole Nationale Superieure d'Informatique et de Mathematiques Appliquees, Laboratoire d'Informatique Fondamentale et d'Intelligence Artificielle, *Dr. C. Laugier* and Dr. J. Crowley.

[11] Ecole Nationale Superieure de Mecanique, Laboratoire d'Automatique, *Prof. W. Khalil,* Professors J.F. Le Corre, J.C. Bardiaux, M. Gautier and P. Chedmail.

[12] Institut Industriel du Nord, Ecole d'Ingenieurs, Laboratoire d'Automatique et d'Informatique Industrielle, *Prof. Gentia* and Prof. Borne.

[13] Institut National Polytechnique de Grenoble, Computer Integrated Manufacturing Center (A.I.P.), *Prof. C. Foulard.*

[14] Institut Universitaire Technologie, Dept. Genie Mechanique et Productique, *Prof. G. Coeurdeuil,* Professors A. Glumineau and P. Vachot.

[15] Universite P. et M. Curie - IMTA, Laboratoire de Mecanique et Robotique, *Prof. J.C. Guinot.* In collaboration with Prof. A. Barraco of the Ecole Nationale Superieure d'Arts et Metiers, Laboratoire de Robotique, and Prof. P. Coiffet of the Institute National des Sciences et Techniques Nucleaires - Cen Saclay.

[16] Universite Paris-SUD, Institut Universitaire de Technologie, *Prof. L. Pontnan.*

[17] Universite de Valenciennes et du Hainaut-Cambresis, Laboratoire de Genie Industriel et Logiciel, *Prof. R. Soenen,* Professors Hioll, Angue, Tahon, Sallez and Wibaut.

Greece

[18] National Technical University, Control and Robotics Group, Computer Engineering Division, *Prof. S. Tzafestas*. In collaboration with Professors G. Stassinopoulas (NTUA), N. Theodorou (NTUA), G. Botsaris (Air Force Acad.), T. Piminidis (Patras Univ.), Dr. P. Stavroulakis (ATNT), Dr. G. Frangakis and Dr. C. Zikides (both of NRC, "Demokritos"). A number of other collaborators in different countries are also involved in this program.

Italy

[19] Universita degli Studi di Roma "La Sapienza", Dipartimento di Informatica e Sistemistica, *Prof. F. Nicolo.*

Japan

[20] Chiba University, Dept. of EE, *Prof. T. Mita,* Professors T. Totani and K. Nonami.

[21] Hosei University, Dept. of Industrial and Control Engineering, *Prof. K. Hirota.*

[22] Tokyo Institute of Technology, Dept. of Control Engineering, *Prof. K. Hasegawa* and Prof. M. Mori

United States of America

[23] Boston University, Dept. of Aerospace and Mechanical Engineering, *Prof. J. Bailleul,* Professors H. Scudder and A. Waxman.

[24] Brown University, Division of Engineering, *Prof. W.A. Wolovich* and Prof. L.B. Freund.

[25] Clemson University, Dept. of Electrical and Computer Engineering (ECE), *Prof. J.Y.S. Luh* and Prof. Y.F. Zheng.

[26] Carnegie - Mellon University, Dept. of Computer Science (CS), *Prof. T. Kanade,* Professors M. Raibert and M. Mason.

[27] Carnegie - Mellon University, The Robotics Institute, *the office of Dr. A.C. Sanderson.* This program is one of the leading robotics research programs in the world, with over 53 faculty members from different engineering departments and a number of visiting staff, graduate students and technical staff. The main thrust of their activities is in automation and computer - integrated manufacturing and robotics for hazardous environments. To include even a brief list of their activities is beyond the scope of this survey. An interested person may directly ask for the Institute's annual research report.

[28] Colorado State University, Dept. of EE, *Prof. G.K. Lee,* Professors M. Andrews, T.A.W. Dwyer, M.B. Histand, G.R. Johnson, M.N. Karim, M.T. Maness, R.A. Mueller, R. Rostampour, W.L. Roy, W.Z. Sadeh, C.W. Smith, F.W. Smith and J.S. Walicki.

[29] Case Western Reserve University, Dept. of EE and Applied Physics, *Dr. F. Merat* and Prof. D. Noeth.

[30] Duke University, Dept. of EE, *Prof. P.P. Wang.*

[31] Florida Atlantic University, Dept. of ECE, *Prof. Z.S. Roth,* Professors R. Sudhakar, R. Floyd (adjunct, IBM), T. Georgiou, R.H. Spencer (adjunct, IBM) and F. Hoffman (Math.).

[32] Georgia Institute of Technology, School of ME (and Computer Integrated Manufacturing Systems Program), *Prof. W.J. Book,* Professors J. Craig (Aerospace), J. Schork (Chem.), L. Emkin (Civil), A. Haddad (EE), D. Fyffe (Industrial), P. Zunde (Information and CS), R. Jeroslow (College of Management) and S. Dickerson (ME).

[33] Harvard University, Division of Engineering and Applied Physics, *Prof. R.W. Brockett,* Prof. Y.C. Ho, Dr. Clark, Dr. Maragos, Dr. Nikoli, Dr. Loncaric, Dr. Wohm.

[34] Louisiana Tech University, Dept. of EE, *Dr. D.K. Fronek,* Dr. Henson and Dr. Cowling.

[35] Marquette University, Dept. of EECS, *Prof. S.H. Wu* and Dr. T.A. Doeir.

[36] Massachusetts Institute of Technology, Dept. of EECS and AI Lab, *Professors W.E.L. Grimson, Lozano-Perez, O. Maimon, Dr. C.G. Atkeson, Dr. C.H. An,* Professors B. Horn, R. Brooks, Dept. of Psych and AI Lab, Professors J. Hollerbach, T. Poggio, S. Ullman, AI Lab, Dr. E. Hildreth, Dr. Bron, Dr. A Yuille, Dr. J. Little, Dr. K. Salisbury, Dr. C. Koch, Prof. W. Richards, Dept of ME, *Prof. K. Youcef-Toumi,* Professors Dubowsky, W. Seering, Hogan, J.J.E. Slotine, Hardt and Sheridan.

[37] Michigan State University, Dept. of EE and Systems Science, *Prof. R.L. Tummala,* Professors Stockman and Jayasnriya.

[38] North Carolina State University, Dept. of ECE, *Dr. R.C. Luo* and Dr. W.E. Snyder.

[39] Northwestern University, Dept. of EECS, *Prof. C.H. Wu.*

[40] New York Institute of Technology, Dept of EE, *Dr. E. Kafrissen.*

[41] Pennsylvania State University, Dept. of ME, *Prof. H.J. Summer III,* Professors Wambald, Tsach, Ray, Sinha and Lamancusa.

[42] Purdue University, Dept. of EE, *Prof. A. Koivo,* Professors S. Ahmad and C.S.G. Lee.

[43] Rensselaer Polytechnic Institute, Dept of ECSE, *Prof. G.N. Saridis,* Professors M. Balas, A. Desrochers, R. Kelley, H. Kaufman and L. Gerhardt.

[44] Rice University, Dept. of ECE, *Prof. R.J.P. DeFigueiredo,* Professors J.B. Pearson, A. Antoulas, F. Briggs, W. Kohn and J.B. Cheatham (ME).

[45] Rutgers University, Dept. of EE, *Prof. G.E. Sevaston.*

[46] Stanford University, Dept. of ME, *Dr. J. Craig,* Professors B. Both, M. Cutkosky, L. Leifer, Dept. of CS, Professors T. Binford, R. Brooks, Dr. O. Khatib, Dept. of Aeronautical Engineering, Professor R. Cannon.

[47] State University of New York at Stony Brook, Dept. of EE, *Prof. M. Eslami*, Professors Sheldon Chang, T. Pavlidis and S. Shapiro. Prof. Eslami is now with the University of Illinois at Chicago, Dept. of EECS.

[48] Tufts University, Dept. of ME, *Prof. A. Saigal.*

[49] University of Arizona, Dept of System and Industrial Engineering, *Prof. D.G. Schultz.*

[50] University of California at Davis, Dept. of ECE, *Prof. T.C. Hsia*, Professors R.C. Dorf, S.H. Wang, T.S. Chang and L. Kou.

[51] University of California at Santa Barbara, Center for Robotic Systems in Microelectronics, *Director Professor Susan Hackwood.* "The Center for Robotic Systems in Microelectronics is a cross-disciplinary center for research and education in robotics and microelectronics. The goal of the CRSM is the advancement of the science and technology of robotic systems through fundamental research in innovative flexible manufacturing processes for microelectronics and through the education of engineers trained in the design as well as analysis of robotic systems." This center is completely supported by NSF under engineering research center programs. The faculty members in this center are: Professors T. Kokkinis, G. Beni, J. Bruch, T. Mitchell, S. Butner, E. Hu, J. Bruno, L.A. Coldren, G. Wade, D. Seborg and D. Mellichamp.

[52] University of Florida, Dept. of Industrial and Systems Engineering, *Prof. E.J. Muth.*

[53] University of Houston, Dept. of EE, *Prof. B.C. McInnis* and Prof. L.S. Shieh.

[54] University of Illinois at Chicago, Dept. of EECS, *Prof. M. Eslami*, Professors G.C. Agarwal, K. Demirbas, D. Graupe, R.V. Kenyon, J.C. Lin and R. Priemer.

[55] University of Illinois at Chicago, Dept. of ME, *Professors K. Gupta and F. Litvin*, Dr. F. Amirouche, Dr. F. Azadivar, Dr. K. Kim, Dr. A. Shabana, Dr. S. Song, Dr. M. Stanisic, Dr. V. Parenti Castelli (visiting from Bologna University in Italy) and Dr. P. Fanghella (visiting from Genova University in Italy).

[56] University of Iowa, Dept. of ECE, *Prof. D.H. Chyung* and Dr. J.H. Lim.

[57] University of Maryland, College Park, Dept. of EE, *Prof. P.S. Krishnaprasad*, Professors Levine, Tits and Abed.

[58] University of Massachusetts at Amherst, Dept. of ECE, *Prof. T.E. Djaferis* and Prof. C. Hollot.

[59] University of Massachusetts at Amherst, Dept of ME, *Prof. B.O. Nnaji.*

[60] University of Michigan, Dept. of Aerospace Engineering, *Prof. N. Harris McClamroch*, Center for Research on Integrated Manufacturing Robot Systems Division, Professors R.A. Volz, D.E. Atkins, G. Frieder, E.G. Gilbert, R.M. Howe, K.B. Irani, R.C. Jain, E. Kannattey-Asibu, Jr., D.S. Kochhar, Y.-C. Lee, E.N. Leith, T.N. Mudge, A.W. Naylor, P. Papalambros, K.G. Shin, D.B. Smith, J.L. Stein, T.J. Teorey, A.G. Ulsoy, T. Weymouth, K. Wise, A.C. Woo, M. Walker and P. Kabamba.

[61] University of Michigan - Dearborn, Dept. of ECE, *Prof. S. Murtuza.*

[62] University of New Mexico, Dept. of ME, *Prof. M. Shahinpoor* and Prof. M. Jamshidi (ECE).

[63] University of Southern California, Computer Science Dept., *Prof. G. Bekey*, Professors R. Nevatia and S. Lee (Dept. EE).

[64] University of Virginia, Dept. of EE, *Prof. R.M. Inigo.*

[65] University of Wyoming, Dept. of EE, *Prof. R.G. Jacqust*, Professors C.T. Constantinides, D.A. Smith and J.J. Cupal.

[66] Washington University, Dept. of System Science and Mathematics, *Prof. T.J. Tarn.*

[67] West Virginia University, Dept. of Mechanical and Aerospace Engineering, *Prof. J.E. Sneckenberger*, Professors R. Nutter and D.T. Lyons.

[68] Yale University, Dept. of EE, *Prof. V. Lumelsky* and Prof. D.E. Koditschek.

Approximately 35% of the above are interdepartmental and 65% are departmental programs.

3. HISTORY

The chart of Fig. 1 shows the history of development of the robotics educational programs in the above institutions. The program that started in 1976 is [22] and that which starts last in 1987 is [54].

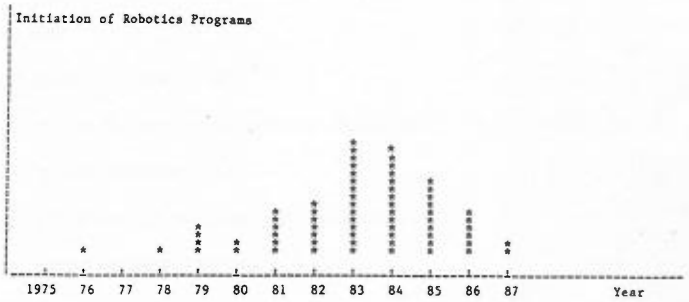

Fig. 1.

4. INDUSTRIAL PARTNERS

The following industrial organizations are partially supporting these programs.

[3] Certain Electronics and space industries.

[4] Robotic Systems International - teleoperator and and robotics manufacturer, International Submarine Engineering, MacMillan.

[7] Bloedel Research, Northern Telecom annual research grant.

[12] Telemecanique and IBM.

[15] A number of industrial firms are supporting this program.

[16] Renault.

[17] ACMA, Citroen, GSD (IBM), ITMI.

[18] A number of European companies within the framework of ESPRIT are contributing to this program.

[28] Martin - Marietta and IBM.

[30] LORD Corporation.

[31] IBM, Motorola, Northern Telecom, Technorate.

[32] Babcox and Wilcox Company, The Coca-Cola Company, DEC, FMC, Hayes Microcomputer Products, IBM, Litton Integrated Systems Technology, Lockheed-Georgia Company, Martin-Marietta Energy Systems, Motorola, NCR, Northern Telecomp, Whirlpool Corporation.

[34] AT&T.

[35] Eaton Corporation.

[36] (Dept. EECS: IBM, DEC, GM, Japanese companies),
(Dept. ME: Some Industrial companies).

[37] GM, Ford, Roberts Corporation.

[38] IBM, Westinghouse, GE.

[41] Hershey Foods, Continental Can, Hewlett-Packard, GE.

[43] DEC.

[46] IBM San Jose, Adept Technology, GM, NASA.

[47] AT&T (Major Computer donation).

[49] DEC.

[50] FMC Corporation.

[51] "The CRSM is strongly committed to support industry in innovative and multidisciplinary research. Formal interaction between the CRSM and industry is accomplished either through the *CRSM Robotic Systems Program* or through membership in *CRSM Industrial Affiliates Program*. In addition, companies, or consortia of companies wishing to make the necessary initial commitment to foster CRSM research along new directions may choose to become *CRSM Sponsors*." "The industrial participants listed below are some of the companies currently interacting or considering interacting with the CRSM under the Industrial Affiliates or Robotics Systems Programs."
AT&T Bell Laboratories, Automatix, Bell Communications, Fairchild, Fluorocarbon, GCA Corporation, GMF Robotics, Hewlett Packard, Hughes, IBM, Integrated Air Systems, Intel, Intelledex, Microbot, Plesscor, Rockwell, Santa Barbara Research Center, Varian.

[52] IBM.

[58] Martin Marietta Aerospace, Denver.

[59] GE, United Technologies, DEC, Raytheom Corp.

[60] Several industrial firms.

[62] Sandia and Los Alamos National Laboratories, Intel, Sperry.

[63] Several industrial firms.

[64] GE.

Many others have only indicated that they have certain collaboration with a number of "local industrial firms," without any specific names.

5. GOVERNMENT OR OTHER FUNDING AGENCIES

Various governmental or other funding agencies are currently supporting directly or indirectly (faculty grant) the above programs. The list is as follows:

[1] The Austrian Government.

[3] National Science and Engineering Research Council, National Research Council, and Ontario provincial government.

[4] Natural Science and Engineering Research Council.

[7] National Science and Engineering Research Council.

[8] Manpower Services Commission.

[9] Finnish Academy, Industry and Technological Development Center.

[11] Ministry of higher education.

[12] Pole productique Region Nord Pas-de-Calais.

[13] Ministere de l'Education Nationale, Ministere de L'Industrie, Etablissement public regional, and Institut National Polytechnique de Grenoble.

[14] Ministere de l'Education Nationale.

[15] Ministere de l'Education Nationale and Ministere de la Recherche et de l'Enseignement Superieur.

[16] Ministere de l'Education Nationale and Ministere de l'Industrie.

[17] Ministere de l'Education Nationale.

[18] European Community and Greek Research and Technology Secretariat.

[20] Special Science Foundation from Japanese Government.

[21] Hosei University.

[23] Air Force.

[25] DOD.

[30] Navy (through microwave Lab).

[32] NSF, NASA.

[33] NSF, ARO, AFOSR, ONR, DARPA.

[34] NSF, ARO, US Army Missile.

[36] NASA, NSF, DOD, System Development Foundation, DARPA, ONR, Air Force.

[37] NSF.

[38] NSF.

[39] NSF.

[41] Navy, NSF.

[43] Navy, Army.

[44] ONR (initial equipment grant), NSF, ONR, NASA.

[46] NSF, SDF (Systems Development Foundation), DOD, NASA.

[50] ONR.

[51] NSF (ERC).

[55] NSF, USARO, Ill-Tech and the Italian Council of Research.

[57] NSF (Laboratory for Computer Controlled System), NASA.

[58] NSF.

[59] NSF.

[60] NASA, NSF.

[63] NASA, NSF.

[64] NSF, AFOSR.

[66] NSF.

[67] National Institute for Occupational Safety and Health Division of Safety Research (Morgantown, WV Lab).

[68] NSF.

6. TEACHING ACTIVITIES

Currently following courses related to robotics are being offered by the institutions listed earlier. This information again is to the large extent accurate although it may not be complete. The description of each course is followed (if provided) in a parenthesis.

[1] Industrieroboter und Handhabungsgerate (presumably a series of graduate courses).
("Types of robots and manipulators; applications and application example; parts of robots (e.g., structure, drives, gears, grippers, internal and external sensors, control equipment); fundamentals of mathematics, mechanics and control; mathematical models for the dynamic behaviour; simulation; model reduction; position control; programming and programming languages; "advanced" control algorithms and concepts (e.g., optimal and adaptive control); application criteria; developments and trends.")
Laboratory: A hydraulically driven robot arm (Feedback HRA), Two PC (commodore 64), one IBM-PC, one 16-bit microcomputer (NCR) plus a number of other computing facilities at the University.

[2] Industrieroboter und Handhabungsgerate.
Laboratory: PUMA 560, Hitachi RM 501, Two PC's.

[3] Introduction to Robotic (U and G).
Robotics and Microprocessors Applications (G).
First Course on Robotics and Vision Systems (U).
Laboratory: Two Rhino robots, Adept robot, Microcomputers, Apollo Network.

[4] ELEC 592 - System Design for Robots and Teleoperators.
MECH 563 - Robotics, Kinematics, Dynamics & Control.

[5] ELG 4195 - Real Time Systems: Robotics (U).
("Introduction to robotics, sensors, transducers, actuators, real-time computer - control systems, applications.")
ELG 5160 - Introduction to Robotics (G).
("Introduction to robots and their applications. Types of robots Power sources: hydraulic, pneumatic and electric systems. Representation of Robot kinematics and dynamics. Planning and execution of manipulator trajectory. Feedback from the environment: the use of sensors and artificial vision. Real-time computer control. Programming languages and programming aspects. Application case studies.")
Computer Systems for Flexible Assembly (G - topics).
("Industrial environment, plants and control strategies, computer/plant interfacing, computer systems for real-time control. Flexible assembly. Multi-sensor, computer controlled, robotic assembly stations. The intelligent connection of perception to action. Structured framework for the control of flexible assembly systems. Assembly systems programming: from manipulator-level to task-level programming. Reasoning about objects, space and tasks. Trajectory, grasp and compliant-motion planning. Automatic programming for flexible assembly.")
Laboratory: ASEA Robot, small motor modules for control with microprocessor - in house design.

[6] ENGINEERING 345 - Robotics and Manufacturing (UG).
("Fundamentals of robots and application concepts of robotics in industry. Fundamentals: types of mechanical, electrical, electronic and software systems. Application: familiarization, specification, selection, economic justification, assessment of work environment and social impact.")
ENME 830 - Robotics (G).
("A comprehensive coverage of the field emphasizing design philosophy and development methodology. Designing, planning, selecting and applying robotic technology with regard to mechanics, dynamics and control, load capacity, repeatability and manipulators. Basic concepts associated with sensors, actuators, sensory, feedback, programming and vision.")
Laboratory: PC, fluid power test stand, small educational robot.

[7] Robotic Based Integrated Systems.
Kinematics and Dynamics of Robots.
Advanced Robotics: Software and Control.
Laboratory: PUMA 560, IBM 7565.

[8] "Robotics is taught as part of diploma course in manufacturing and computer-aided engineering. A course on computer integrated manufacturer (CIM) which includes a significant robotic component is taught in degree programs in: 'Business Studies', also 'Engineering' and 'Technology with Industrial Studies'."
Laboratory: PUMA 560, VAL II, Rediffusion Reflex Robot, Fanuc Robot S, plus various small teaching robots, Grasp robot simulation system-software.

[9] Computer Control of Robots.

[10] Commande et Programmation des Robots.
Methodes de Decision en Robotique.
Laboratory: Two SCEMI robots, plus controllers, sensors and vision facilities.

[11] Robotique.
("Geometry and Kinematic of robots; modeling and dynamic; control and programming of robots; sensors; pattern recognition; AI; real-time control; signal processing; image processing.")
Laboratory: Two industrial robots plus two prototype robots built at home, software: SYMORO (symbolic modeling of robots, designed in this laboratory); EUCLID a CAD system.

[12] Basic course on Robotics.
High level approach (Four Options: Productique, Informatique Industrielle, Automatique and Mech. Eng'g.)
Laboratory: Six robots (three AID and three SIRTES) with micro-computer for basic course, and three industrial robots (AFMA, Cincinnati Milacron and IBM7576) plus a vision processing system for higher-level course.

[13] Robotics.
Vision.
Laboratory: (Robotics) Two IBM 7575 Robots plus AML/2 language. Robot BARRAS- PROVENCE, Robot AID, Palet to stock/unstock (a special hand is developed to achieve this operation). (Vision-Computer-Aided) MATROX PIP1024 Card + IBM PC plus CCD Camera for basic methods of video signal processing and ITMI EDGE 90 Card for video signal processing applied to robotics.

[14] Cours de Robotique.
("History of automation and robotics; structure of robots; transducers and sensors; modeling and control of robot manipulators-languages in robotics.")
Laboratory: SCEMI 6 PO1 - LSI 11/23 - LM Language; SIRTES; prototype six axes robot; micro VAX II.

[15] 3eme Cycle Robotique.
Under this title a number of courses in different areas of robotics are being offered by the staff in the different institutions mentioned in [15].
Laboratory: Robot AID, vision system, actuators and microcomputers.

[16] Industrial Robotics.
Laboratory: Several industrial robots.

[17] Introduction to Robotics.
("History of the robotics development; definition of a robot; Mechanical description; programming; sensors; application in industry.")
General Robotics.
("Robot modeling: geometric modeling, kinematic, inverse model processing, dynamic modeling; electrical and hydraulical actuators, sensors; robot controller; programming.")
Programming of Industrial Robots.
("Introduction to the robotics languages; different levels of languages; study of an end-effector language (LM); the integration of sensors; the use of CAD-Robotics systems, future developments in this field.")
Laboratory: Several robots (Robot Citroen with LM, IBM with AML/2); Vision System; VAX 750, Micro VAX II, IBM PC AT; Software (Vision software CAIMAN, Euclid software for CAD-Robotics studies).

[18] Robotics (Analysis, Dynamics, Control, Sensors, Programming).
Expert Systems and Applications (including Robotics and Control).
Laboratory: Several IBM PC's plus one robot arm that soon will be added.

[19] Plant Automation.

[20] No information is given.

[21] Advanced course in Pattern Recognition.
Laboratory: 32 Bits minicomputer (DS-600/80: Toshiba, Ltd.). Industrial robot arm X2 (RM-5001: Mitsubishi, Ltd.).

[22] Robot.
("What is robot? Industrial robot, history, function and construction, dynamics, control. Robot fingers, degree of freedom and manipulatability, analysis of artificial fingers. Robot sensors, roles of sensors, non-visual sensors, visual sensors, Man-robot-machine system, operating robot, robot in factory automation.")

[23] Robotics, Vision Planning.
Introduction to computer vision.
3-D vision.
Laboratory: IBM 7535, American CIMFLEX, MERLIN, 6-Axis Robot, Argus Vision System, Various mechanism designed and fabricated in house.

[24] Engineering 105 - Robotics.
("An introduction to those basic engineering principles which are fundamental to the analysis and design of robotic manipulators, namely configuration and motion kinematics, static force/torque relations, trajectory planning, dynamics, control, and robotic programming languages. More specifically, the relationships between Cartesian and link configurations and the implementation of various Cartesian trajectories by inverse kinematic equation solvers. The Jacobian and its role in differential motion, force/torque interactions, and the determination of degenerate configurations. The dynamic analysis of manipulator motion via Lagrange's equation of motion. Positional control using "standard" techniques such as PID and feedforward compensation. Also, the classification of robotic manipulators by their construction, motion, and link activation, and their performance evaluation via payload, working range, resolution, repeatability, and accuracy. Laboratory experiments and demonstrations involving actual industrial robots as well as the AML programming language.")
Laboratory: AML programming on IBM PC.

[25] ECE 614 - Analysis of Robotic Systems.
ME 656 - Design and Application of Industrial Robots.

[26] AI: Motion and Vision (currently).
Robotics: Vision, and Robotics: Motion (in near future).
Laboratory: Software and programming.

[27] No information is available.

[28] No explicit courses are given, but several departments in College of Engineering give related courses.
Laboratory: IRB-6 ASEA Robot, Microbots, Rhino robotic arm, a number of other instrumentation and computing laboratories in the college. Several other robots are also built in-house.

[29] EEAP 489 - Robotics I.
("Control of robot manipulators; machine vision and tactile sensing. Homogeneous transformations, kinematic equations, motion trajectories, dynamics, control, image processing, model-based image understanding, characteristics of tactile sensors.")

[30] EE 250 - Introduction to Robotics.
EE 253 - Robotics Control.
EE 251 - Pattern Recognition.
EE 252 - Robotics Vision.
Laboratory: P-50-GE, Microbot, Optometric II-GE, Microbot Mover S, Hero.

[31] EEL 6665 - Robot Manipulators (G).
("Modelling and Control of robot manipulators. Homogeneous transformations, task description, motion trajectories, actuators, mathematical models, feedback control, resolved motion, advanced control topics.")
EEL 6820 - Digital Image Processing.
("Image formation, degradation and restoration of images using digital techniques.")
EEL 6935 - Advanced Robotics (G).
("Theory of manipulation, robot manipulators, computer vision, mechanics of mechanical assembly, task planning and kinematic programming, manipulator geometrics and kinematic performance.")
EEL 6935 - Robotic Applications.
("The role of robots in manufacturing, robot classifications, introduction to robot systems, review of robot applications, robot justification, product design for robotic assembly, how to program robots, material handling/parts feeding/process control, tooling/layout/motion planning, organization for robotics, how to select and develop applications, case studies.") (*Comment:* the last two courses have apparently the same number-the author.)
EEL 5934 - Robotic Instrumentation.
("Structure of robot, robotic actuators, transducers and sensors, data conversion acquisition and manipulation, control of the robot, mechanical transmission systems, tooling and end-effectors, energy sources.")
EEL 5934 - Robot Testing and Evaluation.
("Planning, implementing and controlling the testings and evaluation of products in general and robots in particular.")
EEL 5934 - Engineering Applications of Artificial Intelligence.
EEL 6935 - Expert Systems.
Laboratory: IBM 7540 robot, IBM 7565 robot, IBM EDR robot, 4 educational robots: Rhino, Genesis, Armdoroid, Hero-1, PDP 11/44, Terminal to VAX 11/780, Graphic Terminals.

[32] The computer integrated manufacturing systems (CIMS) program gives a series of core courses in CIMS that are cross listed in several of participating schools. For instance the CIMS required courses are as follows:
CIMS I(G).
("The course familiarizes students with manufacturing issues and the need for improved productivity. The multidisciplinary nature of manufacturing is emphasized by individual and group assignments. The manufacturing topics introduced are categorized into four major course segments: processes, equipment, their capabilities and functions; factory integration and the flow of material and information; product and factory design; and factory control.")
CIMS II.
("This course considers current developments and issues in the technologies for integrated manufacturing, including CAD, electronic communication, and factory control techniques. The course consists of readings from the current literature and student led discussion.")
CIMS Seminar.
("The CIMS Seminar provides a state-of-the-art review of computer integrated manufacturing, including perspectives on research issues, hardware and software needs, reviews of installations, and industry's expectations of graduate education in computer integrated manufacturing.")
In addition to the above a number of elective courses are recommended to students pursuing this course of study. These are as follows.

I. Processes and Design for Manufacture

CE - Robotics & Automated Equipment in the Construction Industry.
ChE 8100 - Advanced Computer - Aided Design of Chemical Processes.
ISyE 4024 - Fundamentals of Materials Handling.
ISyE 6524 - Material Flow Systems.
ME 6239 - Materials for Design.
ME 8403 - Flexible Automation Systems.
ME 8403 - Industrial Robotics.

II. Computer and Communications Hardware and Software

AE - Computer-Aided Engineering and Design Systems.
EE 6092 - Computer Communication Systems.
EE 6154 - Hardware and Software in Manufacturing.
EE 6155 - Computers in Manufacturing.
ICS 6361 - Artificial Intelligence.
ISyE 6845 - Interactive Computer Graphics Applications.
ME 6175 - Fundamentals of Computer-Aided Design.

III. System Dynamics, Measurement, and Control

ChE 8100 - Advanced Process Control.
ChE 8100 - Digital Control of Chemical Processes.
EE 83xx - Sensors and Transducers.
EE 83xx - Dynamics and Control of Robots.
ICS 8113 - Models in Systems Engineering.
ISyE 6302 - Quality Control in CIMS.
ISyE 6835 - Simulation of Manufacturing Systems.
ME 8403 - Feedback Control, Design and Implementation.

IV. Management of Industrial Systems

ISyE 6211 - Analysis and Evaluation of Industrial Projects.
ISyE 6303 - Management of Manufacturing Systems.
ISyE 6101 - Modern Organizations.
MSCI 8403 - Managerial Analysis of CIM.

[33] CS182/282 - Introduction to Robotics.
Part I: Systems, Signals and Simulations, Part II: Robotic Manipulators.
Laboratory: Industrial robot, industrial vision machine, general purpose super mini-computer. Symbolic LISP machine, A/D and D/A equipment. High resolution display.

[34] EE 451 - Robotics and AI.
EE 641 - Image Processing.
Laboratory: Robot with controllers, IBM AT with image processing frame gabler. VAX.

[35] Robotic Systems.
Advanced Robotic Systems.
Laboratory: 5 Microbots, 5 Apple II e, Various vision systems.

[36] EECS 6.801 - Machine Vision (U).
("Deriving a symbolic description of the environment from an image. Understanding physics of image formation. Image analysis as an inversion problem. Binary image processing and filtering of images as preprocessing steps. Recovering shape, lightness, orientation and motion. Using constraints to reduce the remaining ambiguity. Photometric stereo and extended Gaussian sphere. Applications to robotics; intelligent interaction of machines with their environment.")
EECS 6.802 - Robot Manipulation (U).
("Introduces kinematic, dynamic, and spatial constraints on robot motion. Basic considerations in design and application of robot systems. Solving kinematics of robot manipulators. Planning trajectories subject to position, velocity, and acceleration constraints. Using rigid-body dynamics in the control of robots.

Controlling force and compliance in manipulation. Survey of basic issues in robot programming. Development of algorithms for automatic synthesis of robot programs.")
EECS 6.866 - Machine Vision (A) (G).
("Intensive introduction to the process of generating a symbolic description of the environment from an image. Students expected to attend the 6.801 lectures as well as occasional seminar meetings on special topics. Material presented in 6.801 is supplemented by reading from the literature. Students required to prepare a paper analyzing research in a selected area.")
EECS 6.867 - Robot Manipulator (A) (G).
("Intensive introduction to the planning and control of robot motion. Students expected to attend the 6.802 lecturers as well as occasional seminar meetings on special topics. Material presented in 6.802 is supplemented by reading from the literature. Students required to prepare a paper analyzing research in a selected area.")
PSYCHOLOGY 9.370 - Control of Movement in Biological and Robotic Systems (A) (G).
("Synthesizes recent approaches toward motor control in the fields of neurophysiology, artificial intelligence, and systems theory. Topics: understanding the physical plant in biological and artificial systems. Kinematics, statics, dynamics. Actuators and effectors. Control of unconstrained movements: open loop control and trajectory determination. Feedback control and reflexes. Control of constrained movements: handwriting, manipulation, and locomotion.")
PSYCOHOLOGY 9.372 - Movement: Mechanisms and Models (A) (G).
("Research seminar directed at surveying basic concepts and methods in the study of the vertebrate motor system. Reviews current investigations on neural integration in movement control emphasizing spinal cord, cerebellar and cortical mechanisms; arm trajectory formation, physiology, and biomechanics; eye-head and eye-hand coordination; manipulation.")
MECH 2.835 - Design and Analysis of Robotic Manipulators (A) (G).
("Modeling and characterization: brief review of kinematics, statics, and dynamics of mechanical linkages; design and analysis of mechanical structure, actuators/transmissions, and sensors. Control system design; trajectory control, force control, adaptive and optimal control. Planning, programming, and applications; teaching, language, simulators, CAD/CAM links. Emphasizes applications in manufacturing processes.")
Plus many other related courses in several different departments.
Laboratory: Several educational and research laboratories exist to complement this program - no other specific information was received.

[37] Introduction to Robotics.
("Robot configuration and geometry; robot drive systems; kinematics and dynamics; controller design; sensors; computer vision and sensor-based robots. Economic, polytical and social implications, industrial applications.")
Laboratory: Several small robots.

[38] Two courses (no other information is given).
Laboratory: IBM 7535 robot, PUMA 560, Cincinnati T3, HP64000 microprocessor development system, Automatix vision II and various microprocessor stations.

[39] Introduction to Robotics (U).
("Introduction to the basic mathematics of robotics. The topics include the homogeneous transformation, kinematics and kinematic solutions, differential relationships, dynamics, motion trajectory planning, robotics control systems, and programming.")
Advanced Robotic Systems (G).
("The course will discuss different methods of dynamic calculation and robot simulation, design of robot control system, force sensors and compliance, robot programming language, different planning of trajectory, and task planning.")
Laboratory: PUMA 560 and several micro-computers.

[40] Robotic Design.
Laboratory: NYTEC five-axis electric robot arm, Cincinnati-Milacron T3 hydraulic robot, Rhino XR-1 robot, Feedback five-axis arm-mover robot, Heathkit Hero-1, NYIT mobile robots.

[41] ME 456 - Robotic Manipulators.
ME 556 - Advanced Robotic Manipulators.
ME 497B - Computer Vision and Inspection.
Laboratory: GE P50, GE A4, GE PC series 3, Microbot and Vofray on IBM PC, 7 IBM-PC running TUTSIM, ROBTUTOR, PIX TUTOR.

[42] EE 569 - Introduction to Robotics.
("The topics to be covered include: Basic components of robotic systems; Kinematics for manipulators; Selection of coordinate frames; Homogeneous transformations; Solutions to kinematic equations; Lagrangian equations and manipulator dynamics; Motion planning; Position, velocity and force control; Controller design; Digital simulations.")
EE 6XX - Control of Robot Manipulator.
("Control techniques used for manipulators are reviewed. Manipulator models for designing controllers are identified. Controllers are designed so as to make manipulator motion follow a desired path. Performance of manipulator system with controllers will be tested by digital simulation. Analysis of multiple manipulators and design controllers for such robotic systems. Analysis and control of non-rigid manipulators.")
EE 6XX - Sensor-Based Robotic Systems.
("Introduction to mathematical analysis of intelligent robotic systems. Topics include reviews of kinematics, dynamics and control; vision processing techniques; task representation, description and planning; description, representation and identification of three dimensional objects; programming languages; and efficient computational structures.")

[43] ECSE 35.641 - Introduction to Robotics and Advanced Automation Systems.
("Methods of design and operation of general purpose and industrial manipulation systems. Kinematic and dynamic models of mechanical arms. Arm control through coordinate transformations, feedback and microcomputers. Hardware components. Computer software and languages. Robotic vision and sensors. A unified theory for Hierarchically Intelligent Control and Application to advanced automation and the industry of future.")

[44] ELEC 498b/MECH498b - Introduction to Robotics.
("A survey of topics in robotics including kinematics, dynamics and control theory applied to robotics. Lecturers are given on image processing and computer vision, voice synthesis and speech recognition, artificial intelligence, and computer robot simulation. Optional laboratory includes programming of Microbot and PUMA robotic arms.")
ELEC 698 - Graduate seminar on Remote Manipulators.
("In this seminar we will discuss recent advances in the modelings and control of remote manipulator systems. We will place special emphasis on the study of techniques for the design and implementation of control schemes for effector trajectory planning, dynamic learning, single and multiple joint motion scheduling, flexible, free play and complianced dynamics compensation, and others. We will discuss several sensor-controller configurations currently in use in the feedback control of remote manipulators with emphasis on the digital on-line processing of sensor signals and the digital generation of control signals. We will illustrate some of the techniques alluded to above, with the aid of an experimental manipulator currently under development in our digital control lab and with data collected from the NASA shuttle remote manipulator system maneuvers in Flight 7.")

Laboratory: No information was received.

[45] Control of Robotic Devices.

[46] ME 219 - Introduction to Robotics.
("An introduction to the basics of robot manipulators and a review of current applications. The following topics will be discussed in detail: kinematic structure, coordinate transformations, manipulator solutions, workspace, path selection, control and dynamics, applications, locomotion. Knowledge of matrix algebra and some familiarity with basic control theory and rigid body mechanics suggested.")

CS 327B - Introduction to Computer Vision.
("An introduction to machine vision and perception. Image generation, the physics of images and sensors, statistical estimation, binary vision and industrial vision systems, structured light and ranging sensors, stereo vision, scene interpretation and image understanding in intelligent systems, geometric modeling and geometric reasoning, representations of the visual world, computation hardware for high speed image understanding, psychophysics. Prerequisites: statistics, knowledge of programming in Pascal, C, LISP, or FORTRAN; linear algebra, orthogonal polynomials.")
CS 372C - Advanced Robotics.
("The emerging field of intelligent robot control systems will be introduced. Robot programming systems, geometric modeling, off-line simulators, integration with CAD data bases, geometric reasoning, assembly planning, sensory integration, collision avoidance, grasping, mobile robots, force strategies, uncertainty analysis, representations for spatial reasoning.")
Advanced Robotics.
("Roughly speaking this course covers: Advanced Control Systems for manipulators. Control in operational space. Redundant manipulators. Force control strategies. Adaptive control. Sliding moded control. Advanced kinematics and dynamics for manipulators.")
There are also a number of one-unit seminars given mostly by outsiders each year.
Laboratory: There is not a general teaching laboratory at Stanford, but the following research laboratories are used occasionally for teaching purposes.

A. Hand-Eye group (aka, Robotics Group) (formerly the Stanford AI Laboratory).
   Directed by Prof. Binford. Usually 2-3 research scientists (postdoctorals), and about 20 students work in the area of computer vision, mobile robotics, and manipulation.
B. CDR Laboratory ("Center for Design Research").
   Directed by Prof. Leifer. About 2-3 research scientists and about 10 students work in the area of robotics for prosthetic uses.
C. Cannon's Flexible Laboratory.
   Directed by Prof. Cannon, about 12 students work in the area of control of flexible robots. Other faculty (Roth, Cutkosky, *etc.* direct the research of students in the area of robotics, but do not have an experimental laboratory as such.)

[47] ESE 563 - Fundamentals of Robotics I (G).
(This course covers basic concepts fundamental to the analysis and design of robot manipulator systems such as homogeneous transformations of the coordinates; static force/torque relations; kinematic and dynamic equations of robot with their associated solutions of any kind; control and programmings of robots will be studied.)
ESE 564 - Fundamentals of Robotics II (G).
(This course advances ESE 563 with more emphasis on kinematics and dynamics; the interrelation between the Cartesian space and the joint space; trajectomy planning; applications of nonlinear and adaptive control strategies in robotics. Task planning and basic robotics vision will be reviewed.)
Laboratory: PUMA 560 (VAL 1, 3 Input-Output Ports), Major electronic instrumentation testing equipment, AT&T 3B5, 3B2 computers, AT&T 5620 (graphic terminal), several other terminals connected to AT&T 3B20, VAX 11/780. Prototype robot with 4 axes and three-pincer end-effector. Industrial quality conveyor with photosensors and microcomputer based control circuits. These two projects are built in-house.

[48] Plan to start in 1987.

[49] SIE 455 - Introduction to Robotics.

[50] EEC 255 - Robotics Systems (G).
("Introduction to robotic systems. Mechanical manipulators, kinematic, manipulator positioning and path planning. Dynamic of manipulators and optimal control. Computer vision and visual feedback, robot motion programming, and control algorithm design.")
EEC 289F - Advanced Topics in Robotics (G).
("Advanced topics in robot manipulator control, trajectory planning and task planning. Both theories and implementation aspects of these topics will be discussed.")
Laboratory: Three Rhino XR-1 robot arms, PUMA 560, DEC LSI-11/23 microcomputers, DEC LSI-11/73, HP 9836 desktop computer, Intel System 310 microcomputer, DECWRITER LA120 printer terminal, HP 82905B printer, and three terminals. For robot vision: Micron-Eye solid-state camera, PULNIX TM-34K CCD array camera, a Poynting Products, Inc. 505 Video Frame Grabber, an RCA 10 inch color monitor.

[51] ECE 181A - Introduction to Robotics - Robot Mechanics.
("Overview of robot kinematics and dynamics. Structure and operation of industrial robots. Robot performance: workspace, velocity precision, payload. End-effectors structure and operation. Comparative discussion of robot mechanical designs. Actuators. Robot coordinate systems. Kinematics of position. Dynamics of manipulators. Introduction to sensors and control.")
ECE 181B - Introduction to Robotics - Robotic Sensing.
ECE 181 BL - Introduction to Robotics Lab - Robotic Sensing Laboratory.
("Overview of robot sensing technology. Mechanical, acoustic, thermal, electric, magnetic, optical and chemical sensors. Characteristics of sensor devices for robots: sensitivity, resolution and reliability. Emphasis on visual sensors. Imaging and segmentation of objects. Description, recognition and understanding of images. Comparative discussion of robot sensing system designs. Design emphasis on integrating different types of sensors on one robot or robot system.")
ECE 181C - Introduction to Robotics - Robotic Systems.
ECE 181 CL - Introduction to Robotics Lab - Rob. Syst. Laboratory.
("Overview of robot control technology from open-loop manipulators and sensing systems, to single-joint servovalves and servomotors, to integrated adaptive force and position control using feedback from machine vision and touch sensing systems. Comparative discussion of robot control system designs. Design emphasis on accurate tracking and rejection of disturbances accomplished with minimal algorithm complexity and maximal reliability.")

[52] ISE 6555 - Robot Programming and Applications.
("This course comprises formal lectures, reading assignments, programming exercises and laboratory projects. There are two main objectives. One is to give the student an in-depth exposure to the language AML (A Manufacturing Language) and to provide hands-on experience in operating and programming an industrial robot. The other is to gain an overview of the scope of robotic applications in manufacturing.")
Laboratory: IBM 7565 manufacturing system, GCA robot, Intelledex robot, GE Optomation Vision system, AML Software system.

[53] ELEE 6310 - Robotics: Modeling, Kinematic, Dynamic, Controls and Sensors.
Laboratory: PUMA 260; VAL II.

[54] EECS 465 - Robotics Control I.
(Review of basic concepts fundamental to the analysis and design of robot manipulator system; homogeneous transformations of coordinates; force/torque relations; robot modeling, control and programming.)
EECS 466 - Robotics Control II.
(State-space modeling of robotic manipulator; the interrelation between the Cartesian space and the joint space; constrained-optimal trajectory planning; applications of nonlinear and adaptive control strategies in robotics and compliant motion are described with discussion on task planning and robot intelligence.)

[55] ME 310 - Automation and Robotics Applications (U).
("Control and Automation. Programmable logic control. Design of pneumatic and hydraulic systems. Indroduction to theory and design of robots. Robotics applications and demonstrations.")
ME 410 - Analysis and Design of Manipulators (G).
("Description of robotic manipulator; gripper trajectory execution; manipulator design; degrees-of-freedom, solvability, workspace, special link positions; static and dynamic force transmission.")

[56] Introduction to Robotics.
("Introduction to robotics; coordinate transformation; kinematics and inverse kinematics; manipulator dynamics; trajectory planning; manipulator control; force and compliance control; robot programming languages; laboratory projects.")
Laboratory: Rhino robots, IBM PC, VAX 750.

[57] ENEE 769A - Design and Control of Robotic Manipulators.
("This course will be oriented towards laying the mathematical foundations for the study of a variety of problems in Robotics, including multi-fingered hand control, hand-eye machine control, mechanical design of high performance robots, parallel algorithms for inverse kinematics, *etc.* The emphasis in this course will be on careful development of analytical models. The necessary mathematical tools for this purpose will be presented in a systematic manner. We will use some features of the theory of matrix Lie groups, and the Euclidean group will play a prominent role in our development of the subject of inverse kinematics. We will attempt to explore the relevance of this theory for devising parallel algorithms in robotics. The treatment of inverse kinematics will be followed by an exposition of the topic dynamic modeling of robots. We will do this from first principles and present methods base on *multi-body* dynamics. The question of treating joint and link flexibility will be considered in a rigorous manner. We will also discuss the use of symbolic algebraic tools such as MACSYMA and LISP for medeling. Students will have the opportunity to gain hands-on experience with a software package called DYNAMAN developed at the University of Maryland. The software tools will be used for the purpose of illustrating optimization-based mechanical design of manipulators. The subject of manipulator control will be studied in the context of modern control system design methods. Digital control implementation issues will be touched upon. Again computer-aided design methods will be covered and students will gain hands-on-experience with design software. We will also treat some of the basic steps involved in creating *macros* for robot programming in higher level languages; pertinent examples here will be macros for *compliant- move, grasp* and *push*. A major segment of this course will be devoted to the study of design of multi-fingered articulated hands. The work of Salisbury, Kerr, Roth and others will be covered. The approach will be based on a modern treatment of the kinematics of mechanisms using a version of *screw theory*. We will then explore the problem of coordinated control of such hands. The final portion of the course will provide a brief overview of the subject of machine-vision. We will present some algorithms for machine vision that play a useful role in problems such as bin picking and the determination of motion parameters from a single camera. An effort will be made to formulate the hand-eye control problem. It is expected that this course will be accessible to graduate students who have had some preparation in control theory and dynamical systems. We would also like to encourage a small number (<5) of undergraduate students to take this course.")
ENEE 418 - Design Project, Design of MRMS for space station.
Laboratory: one flexible arm experiment, software is now being developed.

[58] ECE 597-G Robotics.
("The field of Robotics is multidisciplinary and can be approached in various ways. In this course we will cover the fundamentals from a control perspective. The course should be a good introduction to more advanced causes in the field and a comprehensive investigation of this relatively new area of interest." Topics: kinematics, force/torque relations, trajectory planning, dynamics and control.")

[59] Industrial Robot Design, Selection and Implementation.

[60] Several courses are given including the following two courses.
ECE 467 - Robot Applications.
("Basic concepts in the organization and operation of microcomputer controlled manipulators. Experiments include kinematics, manipulation, dynamics, trajectory planning and programming language for robots. Applications of computer-controlled robots in manufacturing and programmable automation.")
ECE 567 - Introduction to Robotics: Theory and Practice.
("Methods of design and operation of computer-based robots. Kinematics and dynamics of a six-jointed arm; force, moment, torque, compliance, control methods, trajectory planning. Integration of computer vision systems to form hand-eye coordinated systems. Man-machine communication *via* high-level language.")

[61] Robotics.
Laboratory: Rhinos, Commodore-64, IBM PC.

[62] Robotics.
Robot Engineering I.
Robot Engineering II.
Advanced Robot Engineering.
Robotics Control.
Laboratory: PUMA 560, VAL II; PDP 11/23, ASTEK 6-axis force sensor, vision system with SUN Z/170 graphics, INTEL 310-2 super microcomputer, Rhino XR2-2, INTEL 8748 microprocessor, IBM-PC, IBM 7535 (SCARA) robot arm, and AML software.

[63] No information was received.

[64] EE 525 - Introduction to Robotics.
EE 722 - Robotics
Laboratory: GE P5, two RM 501 (Mitsubishi) and an Optomation Vision System. A precision assembling Allergo with two arms is to be added soon. Vision and symbolic matrix manipulation programs are available.

[65] Introduction to Robotics.
Laboratory: Microbot, Mitsubishi: Movemaster II

[66] Robotics: Dynamics and Control.
Computer-Aided Design and Mechanisms.
Laboratory: Two PUMA 560, VAX 8300, 2 Micro VAX 2, Graphics.

[67] Design of Robotic Systems (U).
Laboratory: Rhino XR-2, GE series 3 programmable controller, GE P50 robot.

[68] Basics of Robotics.
Mathematics of Motion Planning.
Computer Vision.
Pattern Recognition.
Laboratory: Two industrial robots, few educational system, various computer hardware, development stations, terminals, image processing hardware.

6.1. SHORT AND/OR SUMMER COURSES

In addition to the above list of courses the following institutions have certain short and/or summer courses in robotics: [3], [8], [10], [11], [16], [17], [18], [30], [31], [34], [53], [60] and [63]. The total number of students taking these courses per academic year are, 2197 graduate and 1380 undergraduate, respectively. For more information about these courses, please contact the respondent of the respective institution.

7. TEXTBOOKS AND REFERENCES

In addition to various instructors' lecture notes and scientific journals around the world, following is a partial list of textbooks that are being used by those who have responded to our questionnaire to teach the corresponding courses.

- J.S. Albus, *Brains, Behavior, Robotics*. Peterborough, NH: BYTE Books, Subsidiary of McGraw-Hill, 1981.
- H. Asada and J.J.E. Slotine, *Robot Analysis and Control*. New York: Wiley and Sons, 1986.
- H. Asada and K. Youcef-Toumi, *Direct-Drive Robot: Theory and Practice*. Cambridge, MA: MIT Press, 1986.
- C.R. Asfahl, *Robots and Manufacturing Automation*. New York: Wiley, 1985.
- D.H. Ballard and C.M. Brown, Eds., *Computer Vision*. Englewood Cliffs, NJ: Prentice-Hall, 1982.

- M. Brady, *et. al*, Eds., *Robot Motion, Planning and Control.* Cambridge, MA: MIT Press, 1984.
- M. Brady and R.P. Paul, Eds., *Robotic Research: The First International Symposium.* Cambridge, MA: MIT Press, 1984.
- K.R. Castlemen, *Digital Image Processing.* Englewood Cliffs, NJ: Prentice-Hall, 1979.
- P. Coiffet, *Robot Technology: vol. 1, Modeling and Control.* Englewood Cliffs, NJ: Prentice-Hall, 1983.
- P. Coiffet, *Robot Technology: vol. 2, Interaction with the Environment.* Englewood Cliffs, NJ: Prentice-Hall, 1983.
- J.J. Craig, *Introduction to Robotics, Mechanics and Control.* Reading, MA: Addison Wesley, 1986.
- A.J. Critchlow, *Introduction to Robotics.* New York: MacMillan, 1985.
- K. Desoyer, P. Kopacek and I. Troch, *Industrieroboter und Handhabungsgerate (Industrial Robots and Manipulators).* Munich, West Germany: R. Oldenbourg, 1985.
- E.C. Fitch and J.B. Surjaatmadja, *Introduction to Fluid Logic.* New York: McGraw-Hill, 1978.
- R. Forsyth and R. Rada, *Machine Learning: Applications in Expert Systems and Information Retrieval.* New York: Halsted Press, 1986.
- K.S. Fu, R.C. Gonzalez and C.S.G. Lee, *Robotics: Control Sensing Vision, and Intelligence.* New York: McGraw-Hill, 1987.
- J.W. Gonzalez and P.A. Wintz, *Digital Image Processing.* Reading, MA: Addison Wesley, 1977, second edition 1984.
- B. Goria and M. Renaud, *Models des Robots Manipulateurs - Application a leur Commande.* Cepadues Publishing Company (no other information).
- M. Groover, M. Weiss, R. Nagel and N. Odrey, *Industrial Robotics.* New York: McGraw-Hill, 1986.
- H. Hanafusa and H. Inoue, Eds., *Robotics Research: The Second International Symposium.* Cambridge, MA: MIT Press, 1985.
- E.J. Haug, *Computer-Aided Analysis and Optimization of Mechanical Systems Dynamics.* New York: Springer-Verlag, 1984.
- F. L'Hote, J.M. Kauffmann, P. Andre, J-P. Tillard, *Robot Technology: vol 4, Robot Components and Systems.* Englewood Cliffs, NJ: Prentice-Hall, 1983.
- E. Kafrissen, *Industrial Robots and Robotics.* Englewood Cliffs, NJ: Prentice-Hall, 1984.
- M.D. Levine, *Vision in Man and Machine.* New York: McGraw-Hill, 1985.
- A. Liegois, *Robot Technology: vol. 7, Performance and Computer-Aided Design.* Englewood Cliffs, NJ: Prentice-Hall, 1983.
- R. Nevatia, *Machine Perception.* Englewood Cliffs, NJ: Prentice-Hall, 1982.
- B.O. Nnaji, *Computer-Aided Design, Selection and Evaluation.* New York: Elsevier, 1986.
- M. Parent and C. Laurgeau, *Robot Technology: vol. 5, Logic and Programming.* Englewood Cliffs, NJ: Prentice-Hall, 1983.
- R.P. Paul, *Robot Manipulators; Mathematics, Programming and Control.* Cambridge, MA: MIT Press, 1982.
- R. Prajoux, H. Farreny and M. Ghallab, *Robot Technology: vol. 6, Decision Autonomy and Artificial Intelligence.* Englewood Cliffs, NJ: Prentice-Hall, 1985.
- P. Ranky and C.Y. Ho, *Robot Modelling: Control and Applications with Software.* Bedford, UK: IFS Publishing, 1985.
- W. Reitman (Ed. M. Ginzberg), *Artificial Intelligence Applications for Business.* Norwood, NJ: Ablex, 1984.
- G.N. Saridis, Ed., *Advances in Automation and Robotics.* Greenwich, CT: Jai Press, 1986.
- W.E. Snyder, *Industrial Robots: Computer Interfacing and Control.* Englewood Cliffs, NJ: Prentice-Hall, 1985.
- R.H. Spencer, *Planning, Implementation and Control in Product Test and Assurance.* Englewood Cliffs, NJ: Prentice-Hall, 1983.
- R.H. Spencer, *Computer Usability Testing and Evaluation.* Englewood Cliffs, NJ: Prentice-Hall, 1985.
- J. Vertut and P. Coiffet, *Robot Technology: vol 3, Teleoperations.* Englewood Cliffs, NJ: Prentice-Hall, 1985.
- M. Vukobratovic and N. Kircanski, *Real-Time Dynamics and Control of Manipulation Robots.* New York: Springer-Verlag, 1985.
- M. Vukobratovic and V. Potkojnak, *Dynamics of Manipulation Robots.* New York: Springer-Verlag, 1982.
- M. Vukobratovic and D. Stokic, *Control of Manipulation Robots.* New York: Springer-Verlag, 1982.
- D.A.A. Waterman, *A Guide to Expert Systems.* Reading, MA: Addison-Wesley, 1986.
- P.H. Winston, *Artificial Intelligence.* Reading, MA: Addison-Wesley, 1984.
- P.H. Winston and B.K. Horn, *LISP.* Reading, MA: Addison-Wesley, 1984.
- W.A. Wolovich, *Robotics: Basic Analysis and Design.* New York: Holt, Rinehart and Winston, 1986.
- *Fuzzy Controlled Intelligent Robot* (in Japanese), McGraw-Hill, 1984 (no other information).
- *Image Pattern Recognition* (in Japanese), McGraw-Hill, 1984 (no other information).

8. RECENT PH.D's

Following is a partial list of those who have received their Ph.D's in areas that are related to robotics within the last four years.

[4] Dr. J. Clark. [7] Dr. B. Benhabib. [9] Dr. A. Peltowaa. [10] Dr. J. Troccaz. [11] Dr. J.F. Kleinfinger. [12] Dr. M. Barbez and Dr. M. Rotella. [13] Dr. P. Charles. [14] Dr. B. Paul. [15] Dr. P. Bidaud, Dr. D. Murquet and Dr. S. Zeghloul. [19] Dr. A. DeLuco. [20] Dr. T. Hoshino. [22] Dr. R. Masuda, Dr. T. Mizutani. [25] Dr. K. Parker. [26] Dr. M. Fuhrman, Dr. B. Lucas, Dr. S. Shafer and Dr. D. Smith. [30] Dr. Togai. [33] Dr. J. Loincaric, Dr. A. McIvor and Dr. D. Montana. [36] Dr. Brou, Dr. Grimson, Dr. Hildreth, Dr. Pentland, Dr. Schunk, Dr. Tevzopoulos and Dr. Witkin. [41] Dr. J.R. Bosnik, Dr. S.K. Chittajallu and Dr. G.M. Dick. [42] Dr. Boyer, Dr. Gorman, Dr. T.H. Guo and Dr. C. Stevenson. [43] Dr. M. Leahy, Dr. G.L. Luo and Dr. K. Valavanis. [44] Dr. N. Kehtarnavaz. [46] Dr. J.J. Craig, Dr. R. Golman, Dr. J. Kerr, Dr. D. Lowe, Dr. J. Maples, Dr. S. Mujtaba, Dr. E. Schmitz and Dr. C. Wampler. [47] Dr. H.T. Jeon and Dr. K.Y. Lim. [55] Dr. C.W. Chang, Dr. K. Kazerounian and Dr. Y.J. Lin. [56] Dr. J.H. Lim. [62] Dr. B.C. Chiou, Dr. Y.T. Kim and Dr. A. Meghdari. [64] Dr. T. Tkocik. [66] Dr. Y.L. Chen.

9. FUTURE PLANS

The following list of plans encompasses all suggestions that were received.

(a) It is expected that more cooperation with other departments of the given institutions will be developed in order to enhance the interdisciplinary nature of this field of study.

(b) To seek more industrial involvement in this program and in a number of ways such as developing an industrial advisory board or more direct partnership.

(c) Due to both theoretical and experimental nature of this discipline and the fact that indeed there are a number of different courses taught in different institutions, most programs are expressing their interest in introducing some new courses and/or refining the existing ones. A number of institutions are planning to have courses in manufacturing, AI, sensory development study, to incorporate CAD/Robotics, integration of robot vision in the system. It is almost unanimous that every program is seeking more computer utilizations in its teaching.

(d) To develop and/or to improve laboratory facilities.

(e) To develop automated manufacturing courses, some leading to a master's degree in this field.

(f) It is very desirable to incorporate vision, pattern recognition, AI, and various control methodologics such as adaptive control techniques, intelligent control systems, in order to develop a more intelligent robot. In a way it is expected to use more feedback control and sensors than before.

(g) To further study mechanical issues such as vibration, structural behavior as pertains to robotics.

(h) Some of the directions for future research are in designing multifinger-hand robots as well as high-speed biped walking robots. Also research in multiple robot projects with each robot having multiple sensors and to coordinate hand-eye and parallel vision processing are being considered currently. Some efforts are now devoted in developing a robot metrology laboratory as well as a clean-room facility.

10. PREDICTION

The consensus of those who responded to our questionnaire was that there would be a greater demand from industry for graduates with expertise in robotics and even more so in CIM. Robots will find more applications for high precision jobs, in hostile environments, and there will be more integration into flexible manufacturing systems. It is believed *rightfully* that there will be many interesting problems to study and/or many interesting questions to answer. This is a great field for both experimentation and theoretical studies of many aspects of both engineering as well as social sciences. This field can serve as an example to test the applicabilities of many theoretical control strategies that have not been possible before. For example, it is pointed out that several Japanese companies are now using fuzzy controlled concepts to develop their robots. It is suggested that we must look into system integration emphasizing dynamics, sensors, controllers, *etc.*, and therefore most future efforts in robotics will be concerned with a task level study. A more structural and decentralized approach to control an elementary task must be developed. We must also be careful to attack problems of proper scope. "Things are much different than ten years ago, e.g., it is no longer considered "research" to invent a new robot programming language. Robot manufacturers and large end-users have facilities to push development in many directions. Universities must continue to look for undeveloped ideas." In short, this seem to be an exciting area with a very promising future and it is expanding rapidly.

On the negative side, it was suggested by a few that the industry will not grow as expected although universities are expanding their programs in this field. Much better textbooks are needed. More standardization of this discipline is needed before it gets too late! Finally one respondent said, "I am not sure that there isn't too much emphasis on this "hot" field at the expenses of more fundamental ideas."

11. RESEARCH INTEREST

It is interesting to note that those who responded to our questionnaire have very diverse backgrounds and quite different prime research interests. But they all have come together under one umbrella called "Robotics". This list is the closest that the author could generate based on responses that were received. Each star shows the number of persons in that field, certainly some have multiple interests.

Fuzzy control	*
Coordination of multiple robots	**
Teleoperator system design	**
Assembly line modeling	***
AI	****
Pattern recognition	******
Vision	*********
Control/Real-time, Adaptive, Intelligent	**********
Robotics (modeling) (Mobile)	**********
Flexible arm/Automation	*****
Robot sensors (model-based)	***
Simulation and Modeling (also CAD)	***
Sensory robot assembly	**
VLSI/Electronics	**
Prosthetic devices	*

12. ACKNOWLEDGMENT

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APPLICATIONS OF ARTIFICIAL INTELLIGENCE VI

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