Newsletter of the IEEE Robotics & Automation Society

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Editor: Dr. Michael B. Leahy, Jr.
Air Force Institute of Technology
AFIT/ENG, WPAFB, Ohio 45433
513-255-9269 or
mleahy@blackbird.afit.af.mil
Associate Editors
Prof. A. C. Kak, Purdue University
Dr. Thomas C. Henderson,
University of Utah
Dr. John Baillieul, Boston University

Managing Editor: Ms. Rosalyn Snyder
5630 Lakeside Dr.
Pfafftown NC 27040
(919)922-1633 or
roz@mrips.bgsm.wfu.edu

Society President: Mr. Norman C. Caplan,
National Science Foundation
1992 Conference Chair: Prof. Giuseppe Menga, Technico di Torino, Italy

In This Issue

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CALL FOR PAPERS

SPECIAL ISSUE ON SPACE ROBOTICS

IEEE Transactions on Robotics and Automation

This special issue focuses on the application of robotic technologies and systems to space exploration and to servicing in space. Its primary motivation is to perform a technology assessment and elucidate realistic possibilities for near-term space missions such as the Space Station Freedom; and project into the future for mid-term missions such as Lunar Science and Construction, and for long-term missions to Mars, comets and asteroids. In these missions, robotic systems must often operate remotely from any local human intervention.

Particular emphasis will be placed on issues pertaining (but not restricted) to

Dynamics:	0-g Dynamics of Space Structures; Rover Vehicle Dynamics; Mechanics of Cometary Sample Acquisition; etc.
Communication and Autonomy:	Time delays on the order of a second for earth orbiting systems; a few seconds for Moon-based systems; half hour for Mars-based systems; etc. Other implications of remote operation (e.g., graceful recovery from degraded capabilities, need for survival behaviors, local *vs.* remote decision making, etc.).
Nature of Space Systems:	Robustness, Stability and Repeatability; Design for in-situ Serviceability; Astronaut Compatibility; Flight Testing; etc.
Nature of Space Operations:	In-Space Assembly; in-situ Servicing; Astronaut Assistance; Construction, Science and Survey; etc.

The issue will focus on problems related (but not restricted) to

1. Control (both System and Component Levels)
2. Human-Machine Interface and Operations (for Teleoperation and Supervised Autonomy)
3. Computing Architectures (Hybrid Systems consisting of flight hardware and terrestrial off-the-shelf and special-purpose hardware, limitations on uplink bandwidth, remote-local architectures, architectures for autonomous space operations, etc.)
4. Design (to account for large temperature variations, meeting special redundancy and robustness requirements, etc.)
5. Sensing (in-space, on comets, on planetary surface, etc.)

INSTRUCTIONS FOR MANUSCRIPTS

Six copies of manuscripts should be submitted to the Editor of the ***IEEE Transactions on Robotics and Automation:*** (NOT to the Special Issue Editors). Both the manuscripts and transmittal letter should be clearly marked to indicate that they are being submitted for consideration for this Special Issue. They will be logged and sent to the Special Issue Editors for review. Both full length regular papers and short papers will be considered, subject to the normal *Transactions* page limits. Papers must not have been published previously or submitted for publication elsewhere. The format of a submitted paper, its title, citations, figures and tables must be in accordance with the policy of the *IEEE Transactions on Robotics and Automation.*

IMPORTANT DATES

August 1991	Call for papers published
February 1, 1992	Cut off for automatic consideration of papers
July 1, 1992	Completion of first review cycle for all papers
September 1, 1992	Completion of final review cycle for all papers
October 1, 1992	Selection of papers for the Issue
November 1, 1992	Final review and acceptance by Editorial Board
December 1, 1992	Final manuscripts, figures, etc. to Editor
April 1993	Publication of the Issue

GUEST EDITORS

Antal K. Bejczy
JPL/Caltech, M/S 198-219
Robotics and Automation
Pasadena, CA 91109

Subramanian T. Venkataraman
JPL/CalTech, M/S 198-219
Robotics and Automation
Pasadena, CA 91109

David L. Akin
University of Maryland
Dept. of Aerospace Engineering
College Park, MD 20742

President's Message

Norman C. Caplan
National Science Foundation

The summer is over and fall seems to bring the regular batch of Workshops, Symposia, and Conferences sponsored by the IEEE or other technical organizations. Most of these meetings serve a worthwhile purpose although I personally think there are too many of them. Because the community involved in robotics and automation is diverse, there is a need to communicate, and the meetings will continue to be productive. Technical exchanges and interactions represent an important activity which your Society endorses and supports. Not only is this function a mainstay of the role of the professional Society, but it is the reason most people join our organization, and promote our discipline.

However, in addition to technical changes, I think there is more to be considered.

In the July 1991 issue of this Newsletter, Dr. Brian Carlisle of Adapt Technology Inc. reported on a panel discussion entitled, "Is U.S. Robotics Research of Any Use to U.S. Industry?" Many viewpoints and issues that can't be ignored were expressed by the panel and the audience during these discussions, These issues involve the fundamental role of the University educator and researcher, as well as the roles of large and small industry, and government. However, the economic impact of robots in a manufacturing environment is completely different from robot use in nuclear inspection or undersea exploration or firefighting. A cost-benefit ratio has a completely different meaning when applied to nuclear safety or when applied to painting and deburring. How does the University researcher, who is constantly looking for financial support from either government or private sources, have time to consider these question when he is preoccupied with trying to support his graduate students? How does he worry about this issue when his reward system, at the university level, is a function of the quantity and quality of the papers he publishes and the grant support he receives? In industry, the reward system revolves around the products and the profit. Any CEO will quickly tell you that intellectually stimulating research is a luxury and an expensive one at that.

What is the government's role? In this country, government policy has always stresses the free market with no involvement by government in industrial affairs. The exceptions to this rule only apply to technology needs for activities such as defense or space where the government is the direct consumer of the products or the research.

Technology transfer is a subject of great interest, but in my opinion, very little has been achieved except in isolated cases. The Europeans and Japanese have policies that allow for more direct government involvement in research, development, and product planning and both groups have expressed interest in cooperating with the researchers in the United States. one example of this international cooperation is the International Advanced Robotics Program (IARP) that traces its origins to the Heads of State Economic Summit in Versailles. More can be said about the IARP role in robotics in the future and the role of other international organizations.

Obviously, the commercialization and utilizatlon of intelligent machines represents a difficult sociological, technical, and economic problem. However, the benefits to be derived by mankind are many and advances can be made in a constructive and responsible manner The R&A Society is primarily focused on technology, but as Brian Carlisle points out, there is a need for a much broader interaction among university, industry, and government representatives. I would also like to ask the. membership to provide thoughts on the subject. Interesting and provocative letters will be published in this Newsletter. Good ideas will generate dialogue and new initiatives.

From the Editor's Desk

Michael B. Leahy
U.S. Air Force Institute of Technology

Well, summer must be over, they turned off the air conditioning in the main classroom building today. Teaching a class at one pm is really a challenge now. Speaking of challenges, I will be leaving the academic environment at AFIT, for a leading role in creating the United States Air Force Logistic's Command's Robotics and Automation Center of Excellence (RACE). RACE will begin life at an Air Logistics Center (ALC) in San Antonio Texas. One of our primary objectives is to become a much needed focal point for robotics and automation activities within the USAF. Our initial emphasis is to improve the efficiency of small batch processes commonly found in the remanufacturing environment. If your research interests are in that broad area I am now one of your customers. Once I figure out what our *real* problems are I will let you know and maybe we can work together to solve them. While I am leaving my teaching position I will maintain adjunct status with AFIT and continue to be an active member of the robotics community. That level of activity will include remaining as editor of this newsletter and hopefully still making publishable contributions. Through the wonder of email you will still be able to reach me at the current address. Next issue I should have the direct dial version.

In his column, Norm Caplan talked about the increasingly important theme of university and industrial cooperation. With my new job responsibilities that is now one of my prime concerns. I have to worry the cost benefit ratio for remanufacturing. The technologies we select to implement must solve real shop floor problems, increase productivity, reliability and maintainability. Having jumped over to the other side, I plan on using my academic experience and contacts to help bridge the gap between the shop floor and the laboratory. Therefore I echo Norm's call for interesting and provocative letters about these and other themes for publication in the newsletter. I know many of you have strong opinions on many important topics. Here is your soapbox, climb up and share your views.

You may have noticed that the newsletter is on the hefty side again this issue. Thanks to your continued support we have again been able to publish our maximum size issue. A large portion of the material in this issue is in response to my call for experimental environment papers. That response reflects the international flavor of the society and the newsletter. I would like to thank the authors from AT&T, McGill, Wuppertal, and Nagoya Universities and the Rizzoli Institute, DIST, Scuola St. Anna and University of Genoa for taking the time to share their experiences with us. All of those articles are interesting reading. Hopefully this issue will encourage other researchers to put out the word on their experimental facilities.

With the start of the fall semester the conference season will soon be in full swing. The Calls for papers and Calender of Events sections attest to that. Unfortunately none of us has the time, energy, or money to attend all the events that might prove to be worthwhile. For the folks who stayed at home a brief synopsis of the meeting is a valuable piece of information. Three of our members provide us with that synopsis for the First International Symposium on Intelligent Robotics held in India earlier this year. If you have the opportunity to attend a workshop or symposium please take a moment to jot down your impressions and send them to Rosalyn or me.

The Technical Activities Board (TAB) of the Robotics and Automation Society will be meeting later this fall. As a member of the TAB board I am again extending an invitation for your input on the future technical directions of ***your*** society. Also remember that nominations for the ADCOM are due to Professor Sanderson by October 15, and that proposals for hosting the 1994 conference will be considered at the fall ADCOM meeting. See the summer issue for more details about these and other society affairs.

Best wishes for a healthy and productive fall.

--mbl
September 1991

Toronto CM Lab

The address was omitted from the July article. The authors' addresses are:

Prof. B. Benhabib, Department of Mechanical Engineering, University of Toronto
5 King's College Rd.
Toronto, ON, Canada, M5S 1A4;
Tel: (416) 978 3447 Fax: (416) 978 7753 beno@me.toronto.edu

Prof. K.C. Smith, Department of Electrical Engineering, University of Toronto, 10 King's College Rd., Toronto, ON, Canada, M5S 1A4
Tel: (416) 978 5033
Fax: (416) 978 7423
lfujino@csri.toronto.edu

Call for Nominations: King-Sun Fu Award

The International Association for Pattern Recognition (IAPR) is pleased to call for nominations for the 1992 King-Sun Fu Award in honor of the memory of **Professor King-Sun Fu.** Dr. Fu was instrumental in the founding of IAPR, served as its first president, and is widely recognized for his extensive contributions to the field of pattern recognition.

This biennial award will be given to a living person in recognition of an outstanding technical contribution to the field of pattern recognition, and will consist of a suitably inscribed and framed certificate and a cash amount, the costs of which are borne by interest income from a special fund created for this purpose.

The award recipient is to be selected by the King-Sun Fu Award Committee, with the selection subject to approval of the IAPR Governing Board, upon nomination by a member of a national member society of IAPR and by endorsement of at least five members, representing at least two member societies different from that of the nominator's.

Members of the IAPR Executive Committee, as well as the Award Committee, shall be ineligible for the award and may not serve as nominators or endorsers.

The 1992 award is intended to be presented at the Eleventh International Conference on Pattern Recognition The Hague, The Netherlands 30 August - 4 September, 1992

The nomination should be completed on the Fu Award Nomination Form.. Forms may be obtained from the Fu Award Committee Chairman. Nominations must be received by thc Award Committee Chairman no later than March 1,1992.

For more information, contact: Dr. Saburo Tsuji, Chairman of the Fu Award Committee, Department of Control Engineering, Osaka University, Toyonaka, Osaka 560, Japan, e-mail: tsuji@ce.osaka-u.ac.jp, Fax +81-6-857-7644.

R&A Newsletter FALL ISSUE DEADLINE November 15, 1991

Email submissions are encouraged, but please send hard copy also. Photographs should be black and white prints, not halftone or color prints in order to reproduce well.. Figures accompanying technical articles should be originals if possible. Also, our OCR software does not digest faxes or dim copies well, so please put a new ribbon in your printer!

Last Call for R&A AdCom Nominations

If you wish to submit a nomination for the Administrative Committee Elections, remember the deadline is October 15. (The first Call was listed in the July newsletter.) We need to fill six vacant AdCom positions by election in early February. As stated in the Society Bylaws, anyone can be nominated with petitions signed by twenty-five (25) or more members of the RA Society. These petitions must be received by Professor Sanderson (Address: Electrical, Computer, and Systems Engineering Dept.; Rensselaer Polytechnic Institute; Troy, NY 12180-33590) or the Secretary (Address: Prof. David E. Orin; Dept. of Electrical Engineering, The Ohio State University, 2015 Neil Avenue, Columbus, OH 43210) by November 1, 1991.

It is also possible to be nominated through the Nominating Committee. Just send Mr. Caplan your updated short bio, resume and your areas of expertise.

Proposals for '94 R&A Conference

Proposals for conference sites for the 1994 must be received by Norman Caplan by October 15.

New Arrivals

Congratulations to the following who have completed the Ph.D.

- **Louise Stark,** University of South Florida, December 1990, *Thesis:* Achieving generalized object recognition through reasoning about association of function to structure, *Advisor*: Kevin Bowyer, Currently: Visiting Assistant Professor at University of South Florida, e-mail: stark@csee.usf.edu
- **John Stewman** University of South Florida, December 1991, *Thesis*: Computing the exact perspective projection aspect graph of an object bounded by planar faces, *Advisor*: Kevin Bowyer, *e-mail*: stewman@csee.usf.edu
- **Jue Zheng,** Northeastern University, *Thesis:* Smoothing and Segmentation of Color Images in Computer Images, *Advisors*: Kimon P. Valavanis and John Gauch. *Currently:* UPS Research and Development .

CIRRSE Electronic Newsletter

Rensselaer's Center for Intelligent Robotic Systems for Space Exploration has established an electronic newsletter. If you would like to be added to our electronic mailing list, send e-mail to cirsse-request@ral.rpi.edu. Please inlude your name and postal address as well. We will periodically send you information about new reports, laboratory activities, and conferences. I look forward to hearing from you.

Alan A. Desrochers Associate Director CIRSSE, CII 8015 Rensselaer Polytechnic Institute Troy, NY 12180

New Books

Computer-aided mechanical assembly planning.
Edited by Luiz S. Homem-de-Mello and Sukhan Lee.
Kluwer Academic Publishers, August 1991.

This book compiles in one volume the main approaches and techniques on assembly planning that have been explored until now, including theoretical aspects as well as practical implementation issues. Its 14 chapters, grouped in two parts, are written by specialists in each of the several different approaches and techniques currently being utilized. The first part addresses issues in assembly modeling, and the second part addresses the systematization and computerization of mechanical assembly planning.

The contributors are: Thomas E. Abell, Guillaume P. Amblard, Daniel F. Balwin, Alain Bourjault, Thomas L. De Fazio, Leila De Floriani, Jean-Michel Henrioud, Richard L. Hoffman, Luiz S. Homem-de-Mello, Sukhan Lee, Man-Cheung Max Lui, Amitava Maulik, George Nagy, Aristides A. G Requicha, Jean-Francois Rit, Arthur C. Sanderson, Yeong Gil Shin, Federico Thomas, Joshua U. Turner, Timothy W. Whalen, Daniel E. Whitney, Randall H. Wilson, Jan D. Wolter.

This book provides researchers, engineers, students and scholars interested in automatic assembly planning with a state of the art description of the important concepts, approaches and techniques, as well as with the necessary background for the developments to come

Position Available

Johnson Endowed Chair in Robotics
College of Engineering
University of California, Riverside

The College of Engineering at the University of California, Riverside is initiating a nationwide search to attract an outstanding scholar for the Johnson Endowed Chair in Engineering. The College is emphasizing robotics and manufacturing and we wish to select a prominent leader in engineering who will have a major impact on a wide range of disciplines in the College. The general engineering area is Intelligent Machines, particularly in the area of robotics engineering and may involve conceptual structure, modeling, design and control of intelligent mechanisms with sensory perception. A candidate who is a generalist and can provide innovative inspiration rather than a specialist is preferred. Both applications and nominations are solicited.

The candidate for the Chair should have qualifications commensurate with the academic rank of full professor, in particular:

1) **Research Ability**, demonstrated by distinct contributions in areas such as Mechanisms, Sensory Perception and Intelligence;
2) **Scholarly knowledge**, demonstrated by competence to interact effectively with other institutions;
3) **Professional standing** at the level of Fellowship (or equivalent) in a major professional society;
4) **Commitment to teaching**, demonstrated by interest and the ability to provide high-quality instruction.

Please submit a resume and names of at least three individuals willing to write letters of reference by October 31, 1991 to

Chair of the Search Committee
Johnson Endowed Chair
College of Engineering
University of California
Riverside CA 92521-0425

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Email Directory

Name	Affiliation	Email	FAX
Samir Mital	Univ. Maryland, Baltimore	mittal@umbc3.umbc.edu	301-455-3559
Wang Danwei	City University of New York	edwwang@ntivax.bitnet	
Richard Zurawski	Swinburne Inst. of Tech	rzz@stan.xx.swin	61 3 819 6

Send Email Directory and Calendar items to Rosalyn Snyder, Managing Editor, roz@mrips.bgsm.wfu.edu, 5630 Lakeside Drive Pfafftown NC 270440, 919 922 1633

System Control Architecture for an Advanced Anthropomorphic Manipulator

R.L. Andersson
AT&T Bell Laboratories
Holmdel, NJ 07733

1.Introduction

This article describes the system under development, at AT&T Bell Laboratories in Holmdel, to control a large anthropomorphic robot. The robot will ultimately have two 7-DOF arms, two 3-DOF grippers, a 2-DOF torso, and a 2-DOF camera platform. It is currently being built under contract by the University of Utah's Center for Engineering Design [6]. The joints contain high-accuracy 200000 pulse/rev optical encoders, load cells for force feedback, and powerful hydraulic actuators - 1200 in-lb at the shoulders. The manipulator's high speed, large bandwidth, and the prospects for two arm and whole arm manipulation make sophisticated coupled control mandatory. The overall objective is to develop an effective system to cause such robots to perform useful work.

Unlike most previous work, this project emphasizes the use of as few processors as possible, where each is as fast as possible. To make this possible, I built my own robot control processor. With this processor, or commercial processors coming to market in the near future, many stratagems required in the past, to achieve real-time execution of complex control algorithms, are no longer necessary.

In particular, attempts at low-level parallelization of kinematics or dynamics algorithms, for normal manipulators, onto tightly coupled processor designs is just not an appropriate research topic any more. The same applies to implementation on customized VLSI devices. The bare fact is that several such algorithms can easily be written in "C" and run on a single state of the art processor at kilohertz rates.

The upshot of the continued increase in processor speed is an increase in the granule size of multiple processor systems. True parallel processing becomes less necessary; instead multiple processors implement "distributed processing," where each processor performs a different task, often with significantly different timing requirements.

The idea behind an overall systems architecture is to allocate work among heterogeneous processors such that processors execute tasks for which they are well suited, and such that communications among processors remains efficient.

Despite the large body of research into real-time distributed operating systems, it has been my experience that such software is unnecessary (or even a hindrance) for robotics systems, where tasks are statically allocated with an eye to specialized peripherals, and that simple shared memory communication is not only fast at run-time, but fast to write as well.

Figure 1 introduces the system's organization. It includes the 20 Mflops "C" processor, named JIFFE, a sophisticated robot interface card, OCTET, and a real-time vision card, TRIAX, all of which were developed here at Bell Labs. Although the entire system has multiple processors, they address major functional blocks such as sensing, planning, and control. Only the vision processor might perform parallel processing.

The robot control JIFFE processor performs trajectory generation, kinematics, force or compliance control, dynamics compensation, and simple or advanced servoing algorithms, all at the 1 KHz rate normally reserved solely for the simplest servoing. JIFFE directly drives the robot interfaces across the VME bus. A second JIFFE executes the task program and does pre-motion planning. A separate board, TRIAX, performs the low-level operations for simple 3-D real-time vision, with a third JIFFE processor to perform the pixel-independent 3-D Operations. JIFFE's fast scalar architecture permits its application to other tasks. TRIAX contains four 20 MHz Motorola 88000 RISC processors for medium-grain parallel or distributed processing.

This article will concentrate on describing the system components, but will also examine the port of an entire existing 4-processor PUMA 260 controller onto a single JIFFE processor, quantifying the speed and programming advantages. For additional details, see [3] upon which much of this is based.

2. The JIFFE Processor

JIFFE is designed to execute 20 Mflops on real robot algorithms, but I made sure it could serve as a general purpose processor as well. JIFFE implements the entire C language; I expect 10,000 lines of code in the final servo system alone, so assembly language is completely infeasible

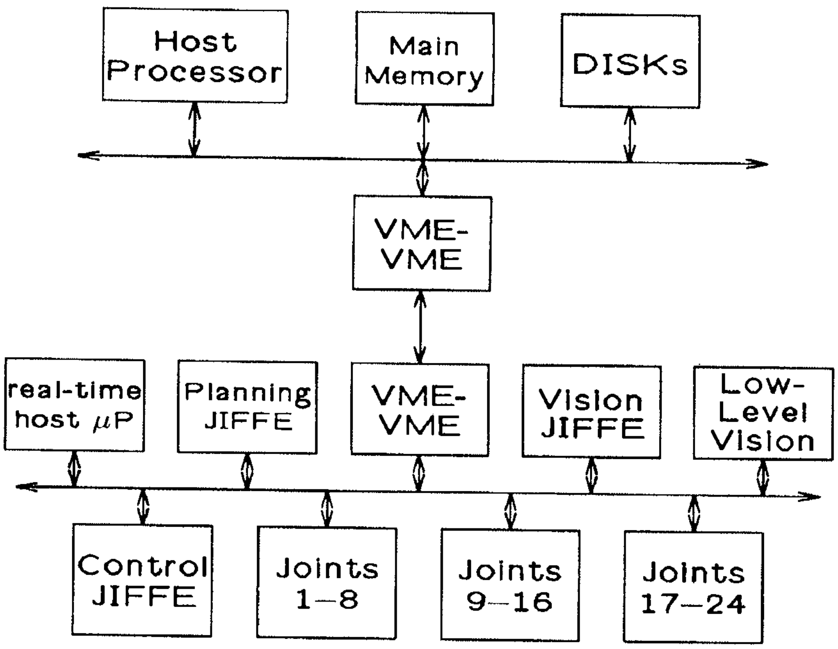

Figure 1. System Organization

and floating point mandatory. Single precision suffices, as the 24 bit mantissa exceeds the encoders' 18 bits. Robot control requires a fast scalar processor that can perform well on secondary support code as well as the primary algorithms. Only a scalar processor can take advantage of simplifications due to matrix symmetries, common subexpressions, zero or one elements, and those arising from automated dynamics minimizers

The JIFFE processor fits on one 37 cm by 40 cm (14.5" by 16") Sun-3 compatible board. Additional details may be found in an earlier paper [2] upon which this section is based.

2.1 VLIW Architecture

I designed JIFFE as a Very-Long-Instruction-Word (VLIW) machine: the compiler produces "microcode" directly. JIFFE's 200 bit instruction word directly controls many parallel units: four memory reads, four register reads, two ALU operations, two register writes, one memory write, and one sequencer operation. JIFFE executes exactly one instruction word each 100 nsec clock cycle. The deterministic timing facilitates real-time programming. JIFFE contains two independent arithmetic-logic units (ALUs) made by Bipolar Integrated Technology (BIT); each ALU contains a multiplier/divider/square-rooter and an adder/logic-operator circuit. At 10 MHz, it processes 20 Mflops. I optimized JIFFE for direct memory references: local variables, parameters, globals, statics, and temporaries; pointer and array references are slower because the address must be computed at run time. JIFFE contains data paths allowing the host to access the on-board program, data, and register files. In addition, JIFFE contains a VME master interface, enabling JIFFE to directly access peripherals, especially robot interfaces, via 'C' subroutine calls.

2.2 Software

The compiler contains a wealth of features: common sub-expression minimization; exploitation of built-in machine-specific features such as *sqrt(x) l*oop unwinding; and a matrix extension. The matrix extension enables quick prototyping of published equations: within the matrix extension I can write $A*B+C$ to invert, multiply A by B, and add matrix C. The extension's 40 Mflops asymptotic matrix multiply and straight- line-coded inverses entice the user. JIFFE will multiply two six by six matrices in 16.2 μsec or invert a six by six matrix in 78.4 μsec. Unlike a vector machine, JIFFE can take advantage of the matrices' properties, such as symmetry or zeroes, to reduce the code.

A *C* library provides an environment similar to that of the UNIX™ (AT&T UNIX Systems Lab) operating system for JIFFE programs, including standard I/O, utility, and VME access functions. The standard I/O routines allow a JIFFE program to read and write data from the host processor's disks or user's terminal, facilitating debugging.

JIFFE's *-lm* library contains such additions as a routine to compute both sine and cosine of an angle in 1.1 μsec, including range reduction.

2.3 Performance

To examine typical performance, I compiled an existing 68020 kinematics and trajectory simulator for a PUMA to run on JIFFE. The unoptimized code contains many control constructs without many long stretches of computation (since there are no dynamics). JIFFE performed at 34 times a Sun 3/260

I also ran a benchmark computing a PUMA's inertial coupling, Coriolis, and centripetal forces using the approach of Izaguirre and Paul [5]. Each loop, including quintic trajectory generation and dynamics, takes a mere 46.9 μsec.

This execution time qualifies JIFFE as a scalar supercomputer: it surpasses a Sun 3/260 by a factor of 134, and a Cray XMP by a factor of 3.

3. Hardware Interface

The robot interface, OCTET, has two major design goals: first, to facilitate minimizing the latency from sensor sampling to actuator signal application, and second, to provide a temporally correct interpretation for all signals.

The overall system latency is the major concern as it impacts servo stability. OCTET emphasizes autonomy, such that only data transfers are required. OCTET packs data into 32 bit words for transfer to maximize bandwidth, but the cost (latency) of packing and unpacking was carefully considered.

All robot interface signals entering or exiting OCTET must have a well-defined temporal interpretation. It is not enough to know that a joint's position attained a certain value, we must know when that occurred, as the joints can move hundreds or thousands of encoder counts per servo clock. Outputs are also a concern, as OCTET must isolate the input-output delay from the vagaries of the software's execution time on a particular pass. Otherwise, the resulting phase jitter degrades the servo loop's stability by adding or modifying velocity-dependent terms. The system must be able to measure the absolute phase to avoid beat frequency problems with other high bandwidth systems, for example, 60 Hz vision systems. I eliminate jitter with a hardware servo clock that causes the contents of all input and output variables to be simultaneously latched to or from temporary registers. To control absolute phase, OCTET schedules all events relative to a global 32 bit clock that counts at 1 MHz, and record event times relative to this clock.

Figure 2 diagrams OCTET's overall structure. OCTET connects to eight robot joints via a cable for each joint. A cable interconnects the multiple OCTETs, carrying clock

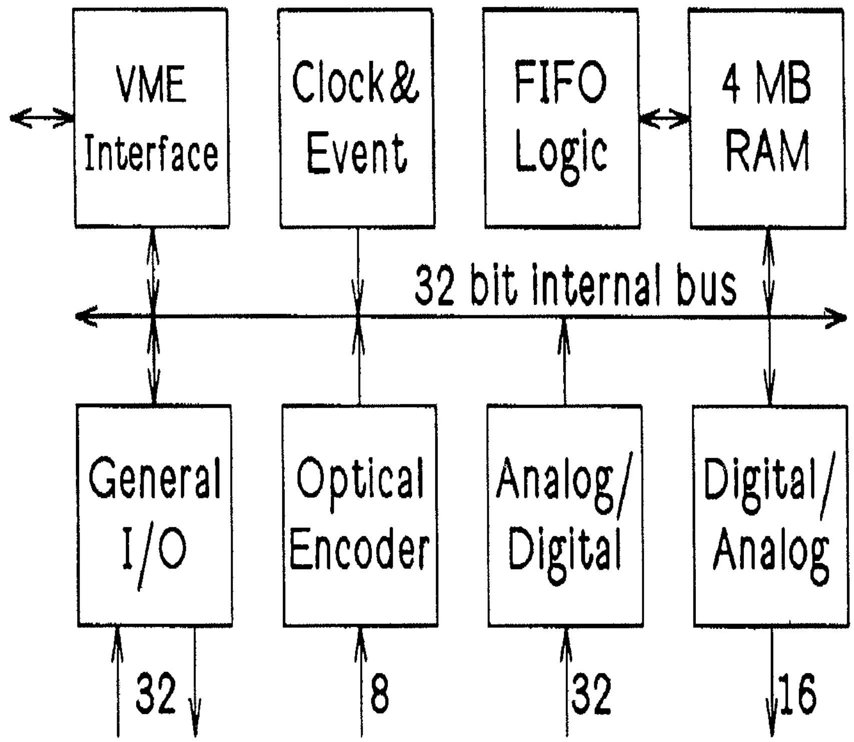

Figure 2: Joint Interface Architecture

and manipulator power sequencing signals. OCTET fits on a 9U by 400 mm DIN card.

OCTET can track an optical encoder-type position for each joint to 16 bits accuracy, additionally monitoring 8 more higher-order bits (24 total), so that position remains available across program crashes. A register stores the encoder count at the start of each servo cycle, synchronous with the A/D sampling, to maintain a consistent view. Only 4 words must be transferred at run time to describe the 8 joints.

An additional circuit records the time at the last encoder transition within a servo cycle. From this data, a clean velocity signal can be computed across the full range of very low to very high velocities.

OCTET digitizes 4 analog signals per joint to 12 bits resolution, to monitor such signals as analog position, velocity, force, voltage, current, and pressure. All 32 channels are digitized within 34 μsec, starting automatically with the servo cycle. Each channel has its own sample and hold, to provide temporal consistency.

OCTET contains two 12 bit D/A channels for each joint. A second clock, delayed from the servo clock by a software-selected interval, drives the D/A converters.

I can set the delay to the maximum time required to compute the D/A values after the servo clock; proper software design minimizes the maximum output latency to 10-20% of a servo cycle, improving system stability. To facilitate debugging, OCTET contains a 4 MB RAM that can be partitioned into two FIFOs and a normal RAM area. OCTET automatically logs most incoming VME transactions into one of the FIFOs, particularly the A/D, D/A, and optical encoder data. This facilitates analysis without execution time penalty.

4. Performance

This section describes the robot control architecture's performance while controlling a 6-DOF PUMA 260 robot. To afford an interesting comparison with more conventional architectures, I ported the robot control software from a robot ping-pong player [1] onto the new architecture.

The previous architecture relied on a tightly coupled network of four Motorola 68020 processors, coupled via shared memory on a Multi-Bus. Two processors each controlled three joints at 1200 Hz, with little time to spare. A third processor computed kinematics, simplified dynamics, and gravity compensation of the evolving trajectory for 10 msec of a 26 msec major cycle. The fourth, primary, processor serviced the secondary processors by moving data among them, requiring 2 msec at the 38 Hz major cycle rate. It executed the user task for the remainder of the period, planning the trajectories and sending them to the secondary processors.

Because of JIFFE's speed and the application's comparative simplicity, I was able to port the entire control package, include all planning and user interface functions, onto a single JIFFE. This requires that all paths through the code take less than 1 msec - it servos at 1 KHz.

The port took less than one week for the 10,000 lines of source. Much of the code was left unchanged; I left the 68020 optimization intact. Straightforward JIFFE optimizations would doubtless further improve the performance of the main computational routines for kinematics and dynamics.

The most significant code added while porting to JIFFE was the main servo routine, which includes all the VME transfers and the PID calculation. The code required 275 total lines, with 134 non-comment lines (NCL, also excluding lines containing only curly braces).

The JIFFE-based architecture significantly reduced the software's overall complexity. The multiprocessor version contains 8289 total lines, versus only 6308 for the JIFFE version. Using multiple processors imposed a 31% code-size penalty. As the rapid port indicates, the uniprocessor version is conceptually simpler as well.

The total execution time per servo cycle varies depending on the type of trajectory being generated at any instant: quintic, joint-interpolated, Cartesian straight line, or transitions between segments. Although there may be some more extreme cases, observed total execution times range from 170-250 μsec, implying trajectory generation, kinematics, and dynamics calculations run in 100-200 μsec.

From the detailed timing, I predict the minimum latency on the full 24 DOF manipulator to be 123 μsec, or a safe 130 μsec, assuming PID on each joint.

5. Vision System

My research objective of high-performance sensory manipulation requires continual sensing of an environment with moving objects. This section outlines a vision system to accomplish this task for known objects in industrial environments; for details see [4].

Visually guided robot control requires not only a high bandwidth of sensor readings, but a low latency as well, so that the overall closed-loop system may achieve a satisfactory bandwidth. Whole-image processing systems can achieve a moderate bandwidth, but have long latencies, making them unsuited for closed-loop control. For example, a system based on PIPE required a four frame internal processing latency [7], with probably another 1-2 frame latency at the complete system level. I designed my system expressly to

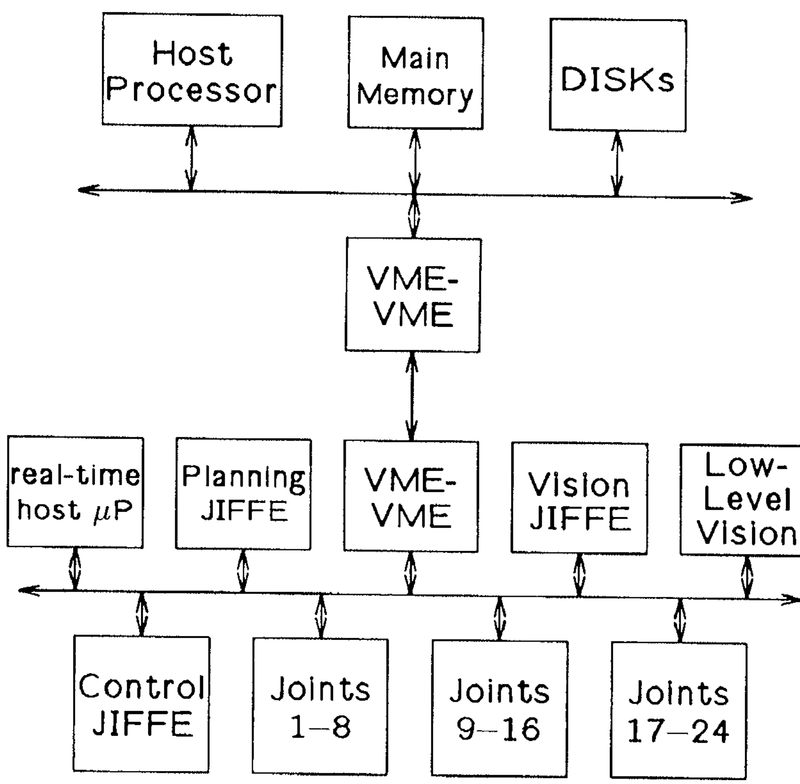

Figure 3 TRIAX Architecture

accuracy, even on rapidly moving objects.

A principal hardware feature is the combination of acquisition and processing on a single board (Figure 3). TRIAX can simultaneously digitize two video streams to 8 bits by 756 pixels by 242 lines by 60 Hz. TRIAX can process several images in the time required to transfer a single image across a VME bus. Four general-purpose Motorola 88000 RISC processors mounted on a Motorola Hypermodule provide the processing power, allowing me to avoid committing a particular algorithm to hardware. The processors and digitizers share a fast 2 MB SRAM memory. The 88000's caches are crucial to reduce the memory bandwidth emanating from multiple processors to a level which will not overwhelm the bus to memory, fast as it is. The 88000's onboard floating-point capability eliminates the board area and performance penalties of off-chip coprocessors.

To achieve real-time operation, the image processing algorithm extracts only the minimum information directly required for control; it does so by examining only a small fraction of the pixels via a focussed analysis-by-synthesis approach.

The software design tracks an object at a known location, rather than analyzing each image from scratch. Only the incremental change must be analyzed; analyzing the images at 60 Hz minimizes the change from frame to frame, in turn minimizing the amount of analysis required. The software examines only a few thousand pixels per frame. Consequently, unknown, unmodeled, background is easily ignored.

As an initial demonstration, I wrote a program that visually tracks a cardboard box at 60 Hz in six dimensions. Only pixels along small "checklines" get examined each frame. The checklines are computed on the fly to intersect the box's visible edges; each edge's location along the checkline is the only data retained. A pose fitting algorithm computes the best object location given the edge locations. A JIFFE robotics processor implements the 3-D calculations, while TRIAX handles the pixel analysis.

The 88000 program runs in approximately 75% of the available time, but the demonstration used only a single 88000 running at 16.7 MHz instead of four running at 20 MHz. (This software was originally run on the prototype wire-wrap version, which ran slower than the final PCB version.) JIFFE's entire processing for a frame, from the time the hit positions become available from TRIAX until the check lines and frame outline have been sent back, requires only 7.2 msec for 108 check lines in and out.

The overall system latency, which determines how rapidly the controller can close an external feedback loop, includes the camera sampling time (4 msec); the camera readout time (16.7 msec); the time for TRIAX to scan the checklines (7.6 msec), but not any of the display handling time; the time for JIFFE to compute a new pose (2.4 msec), excluding any time to compute new checklines; and the time required to change the robot's motion (1.5 msec).

The total latency, 32.2 msec, reflects the critical path from photons to a change in robot state, which in turn affects the photons. The image readout time, determined by the serial analog NTSC format, accounts for the bulk of the time, yet it is the least flexible component. The sampling rate, at which new pose estimates are generated, is 60 Hz.

So far, the experiment must be classified as a feasibility test, rather than a system ready to track objects in complex environments. The system has the processing power to grow into those more complex environments. JIFFE computes only 50% of a frame time; TRIAX works harder at 75%, but this corresponds to under 16% in the final configuration. Terms linearly proportional to the number of checklines dominate the processing time requirement.

6 Summary

I have described a control system designed for a 24 degree of freedom robot, including a 20 Mflops processor for robotics applications, an interface card for eight joints, and a real-time vision card. On a 6 DOF robot, the system demonstrated input to output latencies of 56 μsec, with total trajectory, kinematics, and dynamics computation times under 250 μsec.

At this time, I am working with a 7+3-DOF arm/hand prototype to formulate detailed system models. The 6 DOF controller was ported onto the different redundant kinematics, and can run the figure with joint and Cartesian interpolated motions. I use only one OCTET, so I can control only eight joints at a time. The maximum latency is set conservatively at 110 μsec with somewhat more complex schemes than before, and with some idle time waiting for A/Ds.

I have yet to construct a demonstration integrating the vision system and the manipulator, but it presents no intrinsic difficulties and should be addressed in the near future.

The continuing increase in uniprocessor performance challenges the robotics community to adapt its methodologies and algorithms. Uniprocessor implementations can enhance both a program's longevity and its portability among institutions as well.

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Continued on Page 12

Laboratory of Robotics and Mechatronics: Nagoya University

Toshio Fukuda, Kazuhiro Kosuge, Fumihito Arai

The Laboratory of Robotics and Mechatronics belongs to the department of mechanical engineering, Nagoya University, which has many electro-mechanical industries in its surroundings such as Mitsubishi, Toyota and their allied companies. Our laboratory, at this moment, has three faculty staffs, one engineer, fourteen Ph.D. students, fourteen undergraduate students and visiting research fellows from industries.

The followings are our experimental facilities at this moment:

General Facilities:

1) Industrial manipulators: We have six industrial manipulators for experiments. PCs with their original controllers are used for the control of these manipulators. The PCs are mainly used to integrate the manipulators with external sensors and other systems. Some of the PCs communicates with workstations through our local area network (Ethernet).

2) Computers: Four SUN Sparc Stations and a SUN3/60 are used mainly for simulations. These are connected to the local area network and sometimes used for experiments together with PCs.

3) Vision Systems: We have two vision systems for the research and development of image processing system in the area of the bio-engineering and microrobots. These systems are connected to PCs and controlled by them.

Specialized facilities:

We have developed a lot of robotic systems such as CEBOTs, Self-Organizing End-Effector System, Micromanipulators, Micro-mobile-robot, Man-Machine Cooperative Type of Robot, Brachiation Robot, etc. These robots have been developed at our laboratory and are controlled by PCs for their experiments. We have 19 PCs for this purpose and some of them are connected to the workstations using Ethernet.

Future Directions:

The computer system plays an important role in modern experimental facilities. Our experimental facilities have been developed around workstations and PCs. At this moment, all of the PCs are not connected to the local area network. The use of local area network is very convenient for research activity including experiments. We intend to connect all of the PCs to the local area network for efficient research activity.

A Sparc Station and an experimental computer system including 68030 and i860 are coming to our laboratory soon with a real time UNIX system (VxWORKS) for the complex real time control of robotic systems. This system will be used for teleoperation using multi-arm system..

For more information, contact the authors at the Department of Mechanical Engineering Nagoya University Furo-cho, Chikusa-ku Nagoya 464-01, JAPAN TEL: +81-52-781-5111 ex.4478 Fax: +81-520781-9243 e-mail: d43 13 la@nucc.cc.nagoya-u.ac jp

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Experimental Robotics Research at McRCIM

Frank Ferrie, Vincent Hayward, Margaret Dalziel
McGill University

Inaugurated in 1985, the McGill Research Centre for Intelligent Machines (McRCIM) now comprises 18 faculty members, 30 staff members and over 100 graduate students from the various engineering disciplines (Electrical, Mechanical, Biomedical, and Mining and Metallurgical) and Computer Science. Current research interests span the breadth of the study of machine intelligence: biological vision systems, active vision, speech recognition, kinematics and dynamics of robotic mechanical systems, robot control and programming, telerobotics, microrobotics, computational geometry, trajectory planning, and theoretical systems control.

Early Stages of Experimental Robotics Research

Research in computer vision and systems control at McGill precedes the inception of McRCIM by several years, but a desire to broaden the scope of research interests to include experimental robotics was part of the motivation for creating the Centre. The initial period of robotics research, from 1984 to 1986, grew out of an interest in the problem of automated inspection and repair of small ceramic-substrate electronic circuit boards (hybrid circuits). Much of this work involved developing image processing techniques for the inspection problem, while the robotics projects examined the issues of coordinating a complex machine with several vision sensors, robotic effectors, and a number of inter-connected computers (the eyes, the hands, and the brains: cameras, Pumas, and Vaxes).

Robot Programming and Control: Kali and RCCL} A second stage, which began in 1986 and has just been concluded, involved work in robot programming environments and hardware architectures for robot controllers. This was largely motivated by the new availability of powerful single board computers and commercially supported real-time operating systems. A system for the control and coordination of multiple robots, named "Kali" (after the multi-armed Hindu deity), was designed, built, and tested under a contract with the NASA Jet Propulsion Laboratory. This system, which uses MC68020 processor boards running the VxWorks™ operating system, provides a generic manipulator-independent robot programming environment, and has given rise to a number of commercial applications.

Simultaneously, work continued on another robot programming environment, RCCL (Robot Control C Library), which facilitates the control of multiple robots from UNIX™ workstations. RCCL continues to serve the research community at McGill and elsewhere, and has reached a level of robustness and stability rarely seen in a research environment. This system will remain in operation, taking advantage of the ever increasing power and lower costs of UNIX workstations.

Both RCCL and Kali have been used to support experiments in manipulator programming, manipulator control, visual servoing, compliant motion, dynamic calibration, and teleoperation. In the later case, an experimental input device based on a parallel kinematic arrangement has been constructed.

Active Vision Laboratory (AVL)

The Active Vision Laboratory at McRCIM is one of the facilities to have made use of RCCL in its research environment. The purpose of the laboratory is to provide support for various aspects of research into artificial (machine) vision, with particular emphasis on active vision. The three major components of the laboratory are (1) sensor systems, (2) manipulator and positioning systems, and (3) high performance computational facilities.

AVL: Sensor Systems

Sensors range from conventional CCD arrays to various types of rangefinding systems. Control and data acquisition are handled by a dedicated multiprocessing system, the McGill Sensor Computing Environment (SCE). The SCE allows each device to be encapsulated in a uniform manner provides access from any part of the McRCIM network. Sensors include an NRCC/McGill laser scanning system with a 1 m^3 field of view and 0.2*mm* resolution at closest approach, various CCD television cameras connected to Datacube hardware in the SCE, and various optical and magnetic depth probes.

AVL: Manipulator and Positioning Systems

Sensors are mounted on the end-effector of a Puma 560 robot which is suspended from the ceiling. This greatly simplifies trajectory planning since the workspace of the robot is largely free of obstacles. The two robots are controlled using RCCL software running on a host workstation. As is the case with the sensor systems, the RCCL software provides a high degree of encapsulation for the manipulator systems. Together, the SCE and RCCL environments allow researchers to set up hand-eye coordination experiments

The Institute of Robotics
Wuppertal University, Germany

Karim Tahboub

The Institute of Robotics at Wuppertal University was founded in 1987 as an interdisciplinary unit to facilitate and organize the cooperation of different university departments in the education and the research regarding the robotics field.

A major in robotics has been offered to electrical engineering students since 1988. Currently approximately 20 graduate students and researchers are working toward their doctorate in robotics. Many other students write their master thesis (Diplomarbeit) or their graduation project (Studienarbeit) in this field.

Federal and local government agencies as well as the industry support and sponsor the institute through financing its research activities which include:

- Intelligent robotic systems
- Robots integration in the automation
- Collision avoidance and supervision of the robot cell
- Development of optimal drives
- Real time and parallel processing
- Hierarchical control concepts "Leitebene"
- Development of control concepts for elastic arms
- Robot applications in clean rooms

A fruitful result of the cooperation between the Institute of Robotics and the Institute of Applied Computer Science at the Wuppertal University is the establishment of the mechatronics multidisciplinary program. The plans for this program have been recently approved by the university council, it is expected that students will be able to join this program the next year. Moreover a Connection Machine with 64k processors has been purchased and installed, this enables the members of the two institutes to experiment and run large scale computing tasks where parallel computing is recommended.

Seven professors heading their departments are members of the institute. Their research activities as well as descriptions of their laboratories are briefed here.

•Technical Mechanics and Electromechanical Constructions, Prof. R. Feiertag

Prof. Feiertag performs research on developing grippers with standard elements for flexible gripping purposes. In addition, experiments on the handling of fiber optics are running. The lab is fitted out with a real time holography plant for the analysis of distortion and vibrations, a thermography camera (AGEMA) with the necessary computer, a colour monitor and a colour printer for analyzing thermal images.

•Automation Engineering, Prof. J. Heidepriem

Current research topics related to robotics include:

- The investigation of employing methods of artificial intelligence, of pattern recognition and of neural networks in automation.
- The applications of computer graphics to the animation of robots and manufacturing cells including paralysing the algorithms.
- Industrial communication and automation systems.

Computational resources available for the researchers include

- Graphics workstation Personal Iris 4D/20TG from Silicon Graphics.
- A connection to the Connection Machine across the university computer net.
- Two Transputer networks
- Four 68020/30 Computers with PDOS, OS/9 and UNIX operating systems.
- -Different PC's

•Electrical Machines and Drives, Prof. J. Holtz

The group of Prof. Holtz is concerned mainly with the electrical actuators of the robot, current research topics include the parameter identification, the vector control of three phase drives and the backward transformation in the case of non-aligned axes geometry. The lab is equipped with a VW R 30 6-axis robot, a video camera, an i860 processor for the backward transformation and a TMS 320 C30 processor for computing the path and for the control.

•Communication Technology Prof. F.J. In der Smitten

The group of Prof. In der Smitten is engaged with developing a digital image processing system as well as with the simulation and the real time processing of the reduction of measured and processed data.

The lab is equipped with different cameras, D/A and A/D image signal converters, digital image processing systems and a test signal generator. Many PC's, a Micro VAX II with a digital colour image memory and a VAX II/750 are also available.

•Safety Control Engineering, Prof. P.C. Muller

The lab includes a PUMA 560 robot, a DLR force and moment sensor, a vision system consisting of two CCD matrix cameras, 16 bit and 32 bit CADMUS computers, two APOLLO 4500 and 2500 workstations and different PC's. The original PUMA servo controller and the VAL programming software are to be replaced by a new control system

McGill University (cont.)

with little concern for the underlying hardware. In addition to the two manipulators, the workspace contains a number of servo-controlled positioning stages which can be accessed from either of the two control environments.

AVL: Computational Facilities

Computational facilities consist of SUN Sparcstations and Silicon Graphics IRIS workstations connected through a local area network to the SCE and RCCL hosts. However, because of the large amounts of data generated by the sensor systems, more powerful computational facilities are required with higher bandwidth than provided by the network. A MasPar 1101 data parallel computer with 2048 processors provides the necessary computational support. It is directly coupled to the SCE by means of a VME bus repeater. The present 1 megabyte/sec bandwidth is not satisfactory and is being upgraded to 15 megabytes/sec with a new interface from MasPar.

Future Experimental Robotics Research

The most recent direction of experimental robotics research has been toward the study of a wide range of basic problems in actuation, sensing, control, and manipulator design. To that end, we are implementing a new system with funding from the Institute for Robotics and Intelligent Systems (part of the Network of Centres of Excellence Program of Canada). It is based on a balanced of resources for sensing, data acquisition, computation, and actuation. Sensors include strain gauges, incremental encoders, tachometers, accelerometers, LVTD's, and others, together with their signal conditioning electronics. Computers include Sun workstations for code development, Silicon Graphics workstations for simulation, and digital signal processor boards for real-time computing and high-rate data acquisition. Actuators include electric motors, gear reduction mechanisms, high-performance hydraulic actuators from Animate Systems Inc., linkage arrangements, and flexible beams. It is planned to progressively migrate most of the code developed on our previous hardware platforms so that the new system becomes operational as soon as possible.

The authors may contacted at the McGill Research Centre for Intelligent Machines McConnell Engineering Building, 3480 University ST. Montreal PQ Canada H3A 2A7. (514) 398-4132

Wuppertal University (cont.)

consisting of some 15 transputers which will work in parallel to insure a high performance speed.

The group is working on the following problems:

- •Collision avoidance and path planning.
- •Work cell supervision and fault detection.
- •Control of elastic robots with revolute and/or prismatic joints.
- •Force and position control for manufacturing and assembly tasks.
- • Nonlinear control of robots

•Automation and Technical Cybernetics, Prof. H.A. Nour Eldin

The lab is equipped with a MANUTEC r2 robot with Siemens RCM3 controller, three grippers, two transputer systems for the image processing and for the simulation, a VME bus system with colour frame grabber, a signal processor system to enable for a fast acquisition and processing of the measured signals, two CCD matrix cameras, one CCD line camera and different PC's.

Research activities include:

- •Expert systems in the robotics
- •Robot hierarchical control technology.
- •Robot vision systems
- •Robot simulation and path planning.

•Manufacturing Technology, Prof. S. Stendorf

Prof. Stendorf explores the application of robots in the assembly and manufacturing cells. The lab contains a Mitsubishi Melfa RM 501 robot, a COBRA Archimedes robot, a KUKA industrial robot of 15 kg load and a portal manipulator for loading a lathe machine. Current research subjects include loading of manufacturing units and knotting of manipulation tasks in the assembly field.

For more information, contact Prof. P. C. Müller, Director; Gaussstr. 20, D-5600 Wuppertal 1, Tel: 49 202 439 20 17, Fax: 49 202 439 29 01; Email:
mueller.cyber.urz.uni-wuppertal.dbp.de

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A Laboratory for Computer-Assisted Orthopaedic Surgery[1]

F.Beltramet, P.Dario** M.Fadd***, M. Marcacci*, G.Marcenrot***, S.Martelli G.Sandini*, A.Visani******Istituti Ortopedici Rizzoli, Bologna; **ARTS Lab, Scuola Superiore S. Anna, Pisa; D.I.S.T., *Univ. of Genoa, Italy*

Introduction

The processing of medical images for planning surgical operations is a quite well established technique in current medical practice. Recently, the use of robotic manipulators to be used in association with computer systems for the processing of medical images has been investigate by an increasing number of laboratories for applications in surgery [1-4]. The main motivations which are usually proposed to justify a robotic approach to surgery are:

- **a)the precision of the robot manipulator;**
- **b)minimally invasive access;**
- **c)reduced trauma to the patient;**
- **d) elimination of hazards to theatre staff in radiotherapy; and**
- **enhanced prospects for telesurgery.**

The ultimate result of computer-assisted techniques is expected to be an overall better quality of the intervention. In addition, it has been observed that the quality of medical images which can be obtained by current imaging techniques (such as CT, NMR and ultrasound) is such that the precision available for presurgical planning and simulation often greatly exceeds the precision of surgical execution [5]. Therefore, a robot manipulator can be regarded as a precise surgical tool for enhancing the manual skill of the surgeon. and for assisting him/her in filling the gap between the quality of planning and that of execution.

Although designed for totally different application domains, currently available industrial robots have the precision and reliability to be immediately usable for investigating the execution of a number of different surgical tasks, in particular those in which the operating theatre can be rigidly structured. Brain and orthopedic surgery are areas in which defining fixed reference frames on the patient is relatively easy, thus facilitating the matching of planning with execution.

The need for integrating the image processing capabilities of current computer systems for planning and simulating interventions with the manipulating skills of present robot systems is widely recognized [5,6]. Investigating this problem is the main objective of a laboratory recently established within a research centre associated with a hospital specializing in orthopaedic surgery in Bologna (Istituti Ortopedici Rizzoli). This research activity is carried out in collaboration with two academic institutions in Pisa and in Genoa specializing, respectively. in the robotics and in the image processing aspects of the project.

This paper describes the overall architecture of the laboratory, and outlines the specific problems of orthopaedic surgery that will be addressed.

System Architecture

The design philosophy of the laboratory system architecture satisfies the following requirements:

- **a) Generality.** Although a specific type of intervention has been identified for initial investigation. the architecture is intended not to be dedicated only to those specific tasks. This feature has been pursued based on the assumption that, since in modern medical practice intervention methods are rapidly changing, it would be a serious mistake to design a robot system dedicated to a single surgical procedure.
- **b) Modularity.** The architecture includes a number of subsystems; each of which can be developed (and used) independently, and then integrated in the system;
- **c) Expandability.** The system allows easy integration of new components and subsystems.

A peculiar feature of the architecture is that it emphasizes not only the goal of achieving precision in orthopaedic intervention, but also the possibility of carrying out sensor-driven procedures and of investigating advanced teleoperated intervention.

A block diagram of the system architecture is depicted in the figure.

The main components of the system are a graphic workstation for acquisition and processing of medical images, and two robot manipulators for intervention. The graphic workstation, a SUN 4/470 MVX

[1]This paper was originally presented at the 1991 ICAR, Pisa Italy, © Institute of Electrical and Electronics Engineers

computer. is used to implement both the body and the world models. This system can perform 3D volumetric data manipulation starting from tomographic sequences of bioimages (CT, MR, PET, etc.).

The data input can be obtained by means of a high resolution optical digitizer, starting from radiograms; an interesting possibility is to acquire digital data directly from the system used to analyze the patient. In the present implementation of the laboratory architecture, data are exchanged using magnetic tapes; it is expected, in the future, that the various imaging instruments will be integrated in a real clinical network for efficient data exchange.

Volumetric models can be integrated with additional information obtained by different modalities, such as non contact sensing (for example, airborne ultrasound or laser ranging), and contact sensing (for example, contour following and even palpation [7]). Body models can be manipulated by the physician for simulating and planning surgical procedures.

Manipulation and navigation through 3-D representations of medical objects, for example bones and articulations, are carried out by appropriate human-computer interfaces, such as a mouse, a joystick or a glove. The architecture shown in the figure includes three different human- computer interlaces: a 6 d.o.f. joystick, a hand exoskeleton and a 6 d.o.f. absolute position sensor located at the wrist of the operator. Those interfaces can be used, either individually or in combination, by the surgeon for manipulating 3-D objects, and for simulating and planning surgical interventions [8]. In addition, the above interfaces are fundamental tools for teleoperating the robot manipulators.

The patient model provides the primary input for an additional important characteristic of the system, that is a numeric control milling machine dedicated to the fabrication of custom-made prostheses.

The world model, i.e. the model of the operating theatre, can be obtained by non contact and by contact-based techniques. The present implementation of the system architecture comprises a 2D 1/2 laser range system, and a 6 d.o.f. goniome-

Knee Implant
An Initial Area of Application

Total knee arthroplasty is usually carried out on patients affected by painful arthrosis, rheumatoid arthritis or severe fractures which have caused the partial destruction of the joint. Its surgical goals are pain relief, improved functional mobility, and long- term fixation, but the ultimate performance of the knee implant depends very much on the accuracy of the intervention.

As the medical staff of the laboratory has extensive clinical experience in the field of press-fit knee implant, primarily with the Kinemax Modular Total Knee System™* the problems associated with the implant of this type of prosthesis by robotic techniques have been considered as a first case study. In fact the surgical procedure to be planned and implemented depends very much on the specific model of knee prosthesis which is chosen.

The surgical procedure for implanting the above type of knee prosthesis can be described as follows:

I) Exposure

The knee is exposed through quadriceps tendon splitting incision. The joint is thoroughly debrided of all marginal osteophytes and remnants of both menisci and anterior cruciate ligament are removed to free the proximal tibia. The most critical operation in this step is the protection of the posterior cruciate ligament;

2) Tibial Preparation

The tibia has to be cut with the appropriate depth and posterior slope (approximately 5). Afterwards the hole for the tibial baseplate stem is made;

3) *Femoral Preparation* The distal femoral condyles are cut perpendicular to the long axis of the femur in sagittal plane and should be angled at 7 to the femoral shaft. Furthermore four additional sections with different slope according to the outline of the prosthesis, and the hole for the stem, are made;

4) Patellar Preparation

After removing the patella, its articular facets are resected to create a flat surface. Three holes are made for fixating the prosthesis.

5) Implant

Once the bones have been prepared, the prosthesis is implanted and the stability of the new joint is checked. Friction between the two components of the joint is tested by flexing the knee and the shape of the components is finely adjusted, if necessary, by the surgeon.

*manufactured by Howmedica, a division of Pfizer Hospital Products Group, Inc.

the University of Southern California. Contact: Prof. George Bekey, Chairman, Technical Program Committee, c/o Computer Science Department, University of Southern California, Los Angeles, California 90089-0782

- **October 22-24. 22nd International Symposium on Industrial Robotics** Detroit MI in conjunction with 6th International Service Robot Congress and the International Robots and Vision Automation Show and Conference. *Sponsors:* Robotics Industries Association, National Service Robot Association, Automated Imaging Association, International Federation of Robotics (Stockholm, Sweden) *Contact:* Robotic Industries Association. PO Box 3724 Ann Arbor MI 48106. (313)994-6088.
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Call for Papers

IROS '92

1992 IEEE/RSJ International Conference on Intelligent Robots and Systems

--Sensor-Based Robotics and Opportunities for Its Industrial Applications---

July 7-10, 1992, The Radisson Plaza Hotel, Raleigh, North Carolina, USA

Sponsored by : IEEE Industrial Electronics Society
IEEE Robotics and Automation Society
Robotics Society of Japan (RSJ)
Society of Instrumentation and Control Engineers (SICE)
New Technology Foundation

This is the 5th such technical meeting. IROS meetings have evolved in Japan and for the first time this meeting will be held in the US. The theme of IROS '92 is **Sensor-Based Robotics and Opportunities for Its Industrial Application**

TOPICS:

Papers with new research results are encouraged for submission. Topics of interest include but are not limited to:

- New sensors, new actuators
- Multisensor fusion/integration
- Information technology for sensors
- Teleoperated and autonomous robots
- Mobile robots: design, planning, navigation, and applications
- Distributed multiple robotic systems
- Cellular robotics
- Micro electro-mechanical devices, systems and robotics
- Application of automation and robotics
- Bio-robotics
- Intelligent motion control
- Learning control, fuzzy control
- AI techniques for intelligent robots and systems
- Neural networks
- Hand-eye systems
- Automation systems: design, planning, modeling, evaluation and optimization
- Man-machine interfaces
- Task and motion planning
- Other related topics on intelligence for robots and systems

Workshops and tutorials will be held on Tuesday, **July 7, 1992**. A technical tour of the Research Triangle Park in North Carolina will also be arranged. The program committee is soliciting proposals for workshops, tutorials, and invited special sessions.

PAPER SUBMISSION:

Two types of papers will be considered: 1) Long papers--limited to 25 double-spaced pages, and 2) Short papers--limited to 10 double-spaced pages

DEADLINES

Paper submission due:	**December 1, 1991**
(**four copies** of complete manuscripts for peer review)	
Acceptance notification:	**February 15, 1992**
Final camera ready paper due:	**April 1, 1992**

For those of you who received the first Call for Papers, please note these are revised deadlines.

Submit papers to either of the following Program Co-Chairs:

Avi Kak, Program Co-Chair
School of Electrical Engineering
Purdue University
West Lafayette, IN 47907, USA
Phone: (317) 494-3551
FAX:(317) 494-6440
E-mail:kak@ecn.purdue.edu

Kazuo Tanie, Program Co-Chair
Mechanical Engineering Laboratory, MITI
1-2 Namiki, Tsukuba-shi
Ibaraki-ken, 305, Japan
Phone: +81-298-54-2656
FAX: +81-298-54-2518
E-mail: M1750@MEL.GO.JP

Proposals for workshops, tutorials, and invited special sessions should be submitted by November 1, 1991* to either of the following

Ren C. Luo, General Co-Chair
Box 7911
Dept. of Electrical and Computer Engineering
North Carolina State University
Raleigh, NC 27696-7911, USA
Phone: (919) 737-5193; after July 27, '91, 515-5193
FAX: (919) 737-5523; after July 27, '91, 515-5523
E-mail: luo@eceris.ece.ncsu.edu

Ichiro Masaki, General Co-Chair
Computer Science Dept.
General Motors Research Laboratories
30500 Mound Rd.
Warren, MI 48090-9055, USA
Phone: (313) 986-1466
FAX:(313) 986-9356
E-mail: MASAKI@GMR.COM

The 1992 Japan-USA Symposium on Flexible Automation will be held after this conference (IROS '92) on July 13-15, 1 992 at Parc55 Hotel, San Francisco, CA, USA.

- •July 7-10, 1992 **IEEE International Conference on Intelligent Robots and Systems IROS '92.** Raleigh NC. (*See Announcement*))
- •**July 13-15, 1992 Japan-USA Symposium on Flexible Automation.** San Francisco (*See Call for Papers*)
- •**August 11-13, 1992, IEEE International Symposium on Intelligent Control,** (*See Call for Papers*)
- •**August 12-14, 1992, International Workshop on Emerging Technologies & Factory Automation.** Melbourne, Australia. (*See Announcement*)
- • **August 17-19 1992 8th Int. Conf. on CAD/CAM: Robotics & Factories of the Future,** Univ. of Metz FRANCE. (*See Call for Papers*).
- •**September 7-10, 1992. EURO-DAK '92. European Design Automation Conference.** Hamburg, Germany. (*See Call for Papers*)
- •**September 17-19, 1992. IEEE International Conference on Systems Engineering** International Conference Center, Kobe, Japan. (*See Call for Papers*)
- •**September 15-18, 1992 ICARCV '92: 2nd Int. Conf. on Automation, Robotics, and Computer Vision.** Singapore. (*See Call for Papers*).
- •.**October 1-2, 1992. International Workshop on Intelligent Manufacturing Systems. Dearborn MI.** (*See Call for Papers*)
- •**November 9-13 ISRAM '92: International Symposium on Robotics and Manufacturing.** Santa Fe, New Mexico. (*See Call for Papers*)
- •**November 16-18, 1992. ISMCR'92: Second International Symposium on Measurement and Control in Robotics.** Tsukuba Sc.ience City, Japan. (*See Call for Papers*)
- •**December 16-18, 1992, 31st IEEE Conference on Decision and Control,** Tucson, AZ. (*See Call for Papers*).

Calls for Papers

- • **International Conference on Intelligent Control and Instrumentation (SICICI '92)** Singapore. February 18-21 1992. *Sponsor:* IEEE Singap ore Section Control Chapter. *Submissions:* Professor C. C. Hang, Technical Programme Chairman, SICICI '92. IEEE Singapore Section, 200 Jalan Sultan *11-03 Textile Centre, Singapore 0719. email: fenghcc@nus3090.bitnet
- • **2nd International Workshop on Advanced Motion Control,** March 16-18, 1992 Nagoya Japan. *Sponsor*: IEEE/IES. *Submissions*: Prof. Shigeru Okuma, Nagoya Univ. Japan, Tel: 81 52 781 5111, ext. 6753; FAX 81 52 781 9263.
- •**ECCV2 European Conference on Computer Vision. May 18-22, 1992. Santa Margherita Ligure Italy.** *Submissions*: Send long (~6000 words) or short (~2000 words) by October 15 1991 to Prof. Giulio Sandini, DIST Univ. of Genova, via Opera Pia 11 A, 16145 Genova, FAX 39 10 603 801, e-mail: eecv92@dist.unige.it. Topics of interest are Color, Texture, Stereo, Motion, Image Features, Stereo Motion Cooperation, Active Vision, Shape, Vision-based Control, Hardware Architectures, Applications.
- •**Rensselaer's 3rd Int. Conf. on Computer Integrated Manufacturing.** May 20-22, 1992. Troy New York. ***Sponsors:*** Rensselaer Polytechnic Institute and New York State Center for Advanced Technology in Automation and Robotics. Submissions: Send 4 copies of complete papers to: Prof. Alan Desrochers, Rensselaer Polytechnic Institute, CII 8015, Dept. of Electrical, Computer, & Systems Eng., Troy NY 12180-3590, Ph:(518)-276-6718 FAX: (518)276-8715

The Fifth IEEE Symposium on Computer-Based Medical Systems: June 14-17,1992, Durham, North Carolina. ***Sponsors:*** The Engineering in Medicine and Biology Soc., The Computer

Soc., and The Eastern North Carolina Section of the IEEE. Submit four copies of paper summaries (max. two pages) by December 1, 1991 to Peter Santago, Department of Radiology, Bowman Gray School of Medicine, Medical Center Boulevard, Winston-Salem, NC 27157-1022, phone 919-748-4260, FAX 919-748-2870 e-mail: cbms@mrips.bgsm.wfu.edu.

- **1992 IEEE International Conference on Intelligent Robots and Systems IROS '92. July 7-10,** Raleigh NC. Deadline: December 1, 1991. Submissions: Papers: Avi Kak or Kazuo Tanie. Proposals for Workshops, Invited Sessions and Tutorials: *Ren Luo or Ichiro Masaki See announcement for addresses and details.*
- 1992 Japan-USA Symposium **on Flexible Automation** July 13-15, 1992, San Francisco. *Sponsors:* ASME and Institute of Systems, Control and Information Engineers of Japan. *Submissions*: Send four copies of long and short (600-1000 word summary of research) papers from all countries except Japan by November 15, 1991 to the Program Chairman, Professor Ming C. Leu, Dept. of Mechanical and Industrial Engineering, Rm. 311, MEC, New Jersey Institute of Technology, University Heights, Newark NJ 07152.
- **IEEE International Symposium on Intelligent Control.** Glasgow Scotland, UK. *Sponsor*: IEEE Control Systems Society. *Deadline:* February 15, 1992. ***Submissions: Papers*: Thomas C. Henderson**, Dept. of Computer Science. 3190 Merrill Engineering Building. University of Utah, Salt Lake City Utah 84112. Ph: (801) 581-3601. Fax: (801)581-5843. email:tch@cs.utah.edu.

Proposals for workshops, tutorials, novel working applications, and invited special sessions in Learned Control of Complex Dynamic Systems, Automated Manufacturing, or from CAD and Interactive Graphics: ***Edward Grant,*** The Turing Institute, George House, 36 North Hanover Street, Glasgow G12AD, UK. Ph.: 041-552-2085. email: eddie@turing.ac.uk.

- **International Workshop on Emerging Technologies & Factory Automation.** August 12-14, 1992, Melbourne, Australia. Sponsors: IEEE/IES, Swinburne Institute of Technology. Submissions:*Deadline:* January 31, 1992. *Contact:* Dr. R Zurawski, Laboratory for Concurrent Computing Systems, Dept. of Electrical & Computer Eng., Swinburne Inst. of Tech., PO Box 218, Melbourne 3122. Ph. +61 3 819 8036, FAX +61 3 819 6443, Email rzz@stan.xx.swin.oz.au
- **IAPR: 11th International Conference on Pattern Recognition.** August 30-Sept.3**, 1992.** *Sponsor:* International Association for Pattern Recognition. Four simultaneous conferences: *Computer Vision and Applications* (H.Niemann); *Pattern Recognition Methodology and Systems* (J. Kittler); *Image, Speech and Signal Analysis,* (I.T. Young); *Architectures for Vision and Pattern Recognition,* (V. Cantoni). *Submissions:* 4 copies of extended (2000-2500 word extended abstract via *ordinary mail* by *October 31 1991* to: 11th ICPR Secretariat, Delft University of Technology, Department of Electrical Engineering, PO Box 5031, 2600 GA Delft, the Netherlands. Tel: 31 15 78 60 52; FAX: 31 15 62 20 00; email: •ICPR@ET.TUDELFT.NL.
- **EURO-DAK '92. European Design Automation Conference.** Hamburg, Germany. September 7-10, 1992. *Sponsor:* Gesellschaft fur Informatik, eV and others. Submissions: February 14, 1992. Europe: G. Musgrave, Brunel University, Dept. Elect. Eng., Kingston Lane, Uxbridge, Middlesex UB8 3PH UK; North America: MP Associates, Inc., Euro-DAK;92 Sec., 7490 Clubhouse Rd., Ste. '01, Boulder CO 80301; Asia: S. Goto, NEC Corporation, C&C Research Labs, 1-1 Miyazaki, 4-Chome, Miyamae-ku, Kawasaki Shi, Kanagawa 213 JAPAN
- **IEEE International Conference on Systems Engineering** International Conference Center, Kobe, Japan on September 17-19, 1992. It is the fourth in a series of annual conferences jointly sponsored by Wright State University and the IEEE Aerospace & Electronic Systems Society. This conference is also being co-sponsored by the Pascal Research Institute, Kobe and organized under the General Chairmanship of Professor Kotaro Hirano, Electronics Engineering Department, Kobe University, Japan. The technical program will include, but not be limited to, the following subjects: sensor-based robotics, manufacturing and flexible assembly systems, design methodology for complex systems, human-machine interaction, neural networks and imaging systems, application of AI and expert systems, telerobotics, and control systems. Authors wishing to contribute papers to this conference are invited to send three copies of a 500-word summary to Professor B.A. Shenoi, Electrical Engineering Dept. Wright State University, Dayton, OH 45435. Deadline for submission of 500 word summary: December 15, 1991, Acceptance/ rejection of papers: February 1, 1992 and Submission of full papers: April 15, 1992.
- **ICARCV'92: 2nd Int. Conf. on Automation, Robotics, and Computer Vision.** Singapore. September 15-18, 1992. *Sponsors:* Nanyang Technological University and the Institute of Engineers, Singapore in cooperation with IEEE Computer Society, IEEE Systems Man and Cybernetics Society and IEEE Singapore Chapter. *Submissions:* February 15, 1992. *Contact:* ICARCV '92 Conference Secretariat, Associated Conventions and Exhibitions PTE LTD, 204 Bukit Timah Road # 04-00, Boon Liew Building, Singapore 0922, Tel: (65)732-6839. FAX (65)732 6309. email: emital@ntivax.bitnet.
- **International Workshop on Intelligent Manufacturing Systems.** October 1-2, 1992. Dearborn MI. *Sponsor:* International Federation of Automatic Control. *CoSponsors:* ASME, IEEE Control Systems Soc., SCS, SME. *Submissions*: 5 copies of 800-1000 word abstract by October 15, 1991 to Dr. Naim A. Kheir, IFAC Workshop IPC Chairman, Department of Electrical & Systems Engineering, Oakland University, Rochester, MI 48309-4401 USA.

IEEE International Conference on Systems Engineering

September 17–19, 1992, Kobe, Japan

Sponsored by: The Department of Electrical Engineering, Wright State University, Dayton, Ohio
IEEE Aerospace and Electronic Systems Society
and: The Pascal Research Institute, Kobe, Japan

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K. Youcef-Toumi, MIT

First Announcement and Call for Papers

The IEEE International Conference on Systems Engineering will be held on September 17–19, 1992 at the International Conference Center, Kobe, Japan. The technical program will cover the general topic of systems engineering and will include, but not be limited to, the following subjects:

- sensor-based robotics
- manufacturing and flexible assembly systems
- design methodology for complex systems
- human-machine interaction
- neural networks and imaging systems
- application of AI and expert systems
- control systems
- system modeling and model reduction
- large-scale systems
- telecommunication systems
- digital signal processing
- biomedical systems
- avionics systems
- telerobotics

Paper Submission

Authors wishing to contribute papers to the conference are invited to send three copies of a 500-word summary of their papers to: **Professor Kotaro Hirano, Department of Electronic Engineering, Kobe University, Rokko-dai, Nada, Kobe, 657 Japan (Telephone: 078-881-1212 extention 5111; FAX: 078-881-3622)** or **Professor B. A. Shenoi, Department of Electrical Engineering, Wright State University, Dayton, Ohio 45435, USA (Telephone: 513/873-3527; FAX 513/873-4106).** The summary must clearly specify the contributions of the paper and should be headed with the title of the paper, author name(s), complete mailing address of author(s), and phone/FAX/E-mail numbers. All abstracts must be received by December 15, 1991.

Full papers should be limited to four pages in length. The Proceedings of the conference will include all papers received by the deadline and will be published in English by IEEE under an IEEE catalog number.

Special Sessions

Those who wish to organize special sessions are asked to contact: **Professor Kotaro Hirano** at the above address.

Deadlines

Submission of a 500-word summary	**December 15, 1991**
Acceptance/rejection of papers	**February 1, 1992**
Submission of full papers	**April 15, 1992**

- **ISRAM '92:4th International Symposium and Exhibition on Robotics and Manufacturing.** November 11-13 1992. Santa Fe New Mexico. *Submissions*: Send 3 copies of full-length regular papers or extended abstracts of short papers by October 1, 1991 *Contact*: Dr. Ron Lumia (Robotics), Intelligent Controls Group, Robot Systems Division, National Institute of Standards and Technology, Gaithersburg MD 20899 USA, Tel: 301-975-3452; FAX 301-990-9688, email: lumia@cme.nist.gov or Prof. Joe H. Mullins (Manufacturing), Manufacturing Engineering Program, Farris Engineering Center, College of Engineering, University of New Mexico, Albuquerque, NM 87131 NM 87131 USA. Tel: 505-277-0558; FAX: 505-277-0813.
- **ISMCR'92: Second International Symposium on Measurement and Control in Robotics.** November 16-18, 1992.. Tsukuba Science City, Japan. *Sponsor*: IMEKO. The conference is organized to focus on the international development of robotics. Suggested topics include robotics overviews of national or R&D projects; human factors in robotics; technology; and applications. *Submissions*: The deadline for abstracts is January 10, 1992. *Contact*: Prof. S. Tachi, RACST, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153 JAPAN. Tel: 81 3 3481 4467 FAX: 81 3481-4469.
- **31st IEEE Conference on Decision and Control,** December 16-18, 1992, Westin LA Paloma Resort/ Hotel, Tucson, AZ. *Deadline:* March 1, 1992. *Contact:* Professor T. Basar, Coordinated Science Lab, Univ. of Illinois, 1101 West Springfield Ave., Urbana, IL 61801, (217) 333-3607, (217) 244-1764 (FAX), email: tbasar@markov.csl.uiuc.edu.

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IEEE Robotics and Automation Society Newsletter EDITORIAL POLICIES

We publish news items, letters, 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 reject any contribution which is inappropriate for this newsletter.

Announcements for non-commercial scholarly conferences, workshops, etc. will be published gratis in our Calendar as space is available with priority given to events sponsored by the IEEE Robotics and Automation Society. For-profit short courses and seminars may be advertised at our standard classified or display rates.

For more information about advertising in the newsletter please contact the Managing Editor.

Call for Papers

1992

Japan-U.S.A. Symposium on Flexible Automation

- A Pacific Rim Conference -

Parc Fifty Five Hotel

San Francisco, California, July 13-15, 1992

This biennial symposium, jointly sponsored by the American Society of Mechanical Engineers and the Institute of Systems, Control and Information Engineers of Japan, is aimed at promoting research activities in various areas of flexible automation by providing a forum for the exchange of ideas, presentation of technological achievements, and discussion of future directions, The theme of this symposium is Intelligent Manufacturing. The main topics will include the following areas:

- robotics
- autonomous vehicles
- automated material processing and assembly
- manufacturing process control
- computer-integrated manufacturing
- communication and software systems
- fuzzy inference and neural networks
- mechatronics
- CAD/CAM/CAE
- sensing and signal processing
- reliability and malfunction analysis
- flexible manufacturing systems
- planning and scheduling for manufacturing
- expert systems and artificial intelligence

To submit papers, four copies of manuscripts from all countries except Japan should be sent by November 15, 1991 to the Program Chairman, *Professor Ming C. Leu, Department of Mechanical and Industrial Engineering, Rm 311, MEC, New Jersey Institute of Technology, University Heights, Newark, New Jersey 07102, USA.* Manuscripts from Japan should be sent by November 15, 1991 to Program Vice-Chairman, *Professor Hiroyuki Tamura, c/o The Institute of Systems, Control and Information Engineers, Kinki-chiho Hatsumei Center, Yoshida-Kawahara-cho 14, Sakyo-ku, Kyoto 606, JAPAN.* All papers should be in English. Both long and short papers will be considered. A long paper is a complete manuscript including an abstract, and a short paper is a 600-1000 word summary of research. Authors will be notified of paper acceptance by March 1, 1992. Final papers on camera-ready mats received by April 15, 1992 will be included in the Symposium Proceedings published by ASME.

Post-symposium tour arrangements will include visits to educational and research institutions such as the University of California at Berkeley, Stanford University, SRI International, NASA Ames Research Center, Lawrence Berkeley Laboratory, and Lawrence Livermore Laboratory. Also to be arranged is an all-around sampling of the best entertainment the bay area has to offer for the spouse program.

Call for Papers
IEEE International Workshop on
Emerging Technologies and Factory Automation

-Technology for Intelligent Factory-

August 12-14, 1992, Melbourne, Australia

Sponsors:

Industrial Electronics Society
Swinburne Institute of Technology, Australia

In cooperation with:

Applied Computer Research Institute, La Trobe University, Australia
Australian Computer Society
Institution of Engineers, Australia

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A qualitative change is taking place in the area of factory automation with the advent of "intelligent factory". This is characterized by the addition of intelligent components to factory environment. This will provide greater flexibility and productivity with reduced capital outlays in the 21st century. These emerging technologies and their applications to factory environment is the topic of this symposium.

Papers are invited on the following methodologies and applications, but not limited to:

-Neural networks: architectures , learning algorithms, applications
-Fuzzy control, learning control, diagnosis
-Temporal and logical reasoning systems
-Genetic algorithm and its application
-AI techniques/expert systems for intelligent robotic and industrial systems
-Petri nets and other techniques for modelling and performance evaluation of discrete-event dynamic systems
-Concurrent engineering
-Scheduling and control of manufacturing systems
-Information technology for CIM: software environments, computer architectures
-Factory computer communications: protocol performance and efficiency, LAN, architectures
-Intelligent automation/process automation
-Intelligent robotic systems: task and motion planing, distributed multiple robotic systems, cellular robotics, robot sensing, sensor integration and fusion
-Vision and inspection systems
-Application of parallel or distributed computing to manufacturing and robotic systems
-Software development and tools for manufacturing related systems

Tutorial Sessions:

Tutorial sessions will be offered in parallel on Tuesday, August 11, 1992. These tutorials, which will be presented by industry and academic leaders, will offer participants both an overview and a deeper look into some of the emerging technologies and their applications to factory environment.Tutorials will cover the following topics: expert systems, neural networks, fuzzy control, systematic approach to development of manufacturing systems, intelligent robotics, sensor integration and fusion.

Submission of Papers and Author's Schedule:

Submit an abstract and summary, formatted as follows. First page: title, authors, mailing address of each author, telephone numbers, fax number, email. Second page: title authors, 100 word abstract. Third and succeeding pages: title, 1000-2000 word summary. Submit four copies of each, in English, to the Technical Program Committee Chairman.

Prof. Tharam S. Dillon
Dept. of Computer Science
La Trobe University
Melbourne, 3083, Australia

Paper summary submission due:	Jan. 31, 1992
Acceptance notification	April 1, 1992
Final camera ready paper due	June 1, 1992

For further information contact Dr Richard Zurawski, Dept. of Electrical & Computer Eng., Swinburne Institute of Technology, PO Box 218, Melbourne 3122, Australia. Ph. +61 3 818 8036, FAX +61 3 819 6443, Email rzz@stan.xx.swin.oz.au

MEMBERSHIP APPLICATION
IEEE ROBOTICS AND AUTOMATION SOCIETY

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All others	**$22.50**

3. I am not a member of the IEEE, but I am a member of the following other professional society ______________. I am applying for affiliate membership in the Robotics & Automation Society. **$47.00**

4. In addition to one of the above options, I wish to subscribe to the IEEE Transactions on Neural Networks. **$10.00**

Total amount enclosed: ____________

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Date: ______________

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Endorsement by one IEEE member who knows you professionally

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
IEEE

1992 IEEE INTERNATIONAL CONFERENCE ON

ROBOTICS AND AUTOMATION

Acropolis Convention Center
Nice, France
May 10 - 15, 1992

Sponsored by the IEEE Robotics and Automation Society

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- ABB Robotics - Västeras - Sweden
- Siemens - Münich - Germany

The beautiful "Cote d'Azur" will host the 1992 IEEE International Conference on Robotics and Automation, to be held in Europe for the first time. Presented in an international co-operative environment, the theme of the conference will be "Advances in Information Technology for Robotics and Automation" and it will aim to be a door opening on the new frontier of Machine and System Intelligence, from machine and shop-floor automation to the Integrated Factory, from sensors and mechanical devices to the high level functionalities of third generation robots.

Special topics include but are not limited to the following:

- Modelling, performance evaluation and simulation of discrete-event dynamic systems.
- Scheduling and control of manufacturing systems.
- Information technology for CIM: software environments for design and prototyping, distributed computer architectures, local area networks.
- Concurrent design of products and automated manufacturing.
- Micro electro-mechanical devices and systems.
- Temporal and logical reasoning systems.
- High level man/machine interfaces.
- Robot sensing : vision, touch, range, force; sensor integration.
- Multisensory perception and environment modelling.
- Design and advanced control software for robotic mechanisms.
- Task level planning, programming, reasoning and reactivity, skills acquisition, learning.
- Autonomous manipulation and mobility: geometric reasoning, navigation, motion generation, sensor-based execution, control.
- Multiple robot coordination and group robotics.
- Applications of automation and robotics in industry, construction, medicine, agriculture, etc.
- Teleoperation, telerobotics and autonomous robots for unstructured environments: underwater, space, hostile environments, etc.

A strong industrial participation through exhibits and presentation of projects is expected. Submissions of non-commercial papers describing applications of interest are encouraged from representatives of industry. A video proceedings presenting research results and applications will be prepared.

IEEE Robotics & Automation Society

ROBOTICS AND AUTOMATION

THE INSTITUTE OF ELECTRICAL & ELECTRONICS ENGINEERS, INC.
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PISCATAWAY, NJ 08854

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