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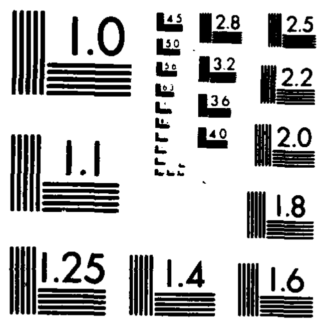

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OFFICE OF NAVAL RESEARCH

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A SURVEY OF EUROPEAN ROBOTICS RESEARCH

SCOTT HARMON
NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA

27 January 1984

UNITED STATES OF AMERICA

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER R-4-84	2. GOVT ACCESSION NO. AD-A138 952	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* A Survey of European Robotics Research		5. TYPE OF REPORT & PERIOD COVERED Technical
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Scott Harmon Naval Ocean Systems Center, San Diego, CA		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Office of Naval Research Branch Office London Box 39 FPO NY 09510		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 27 January 1984
		13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Robotics Research status Europe

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report describes the results of a 1981 survey to gather information about European robotics research that might be tailored to meet the US Navy's needs. The objectives of the study were: (1) to identify key research organizations and scientists, and (2) to determine the nature of the research and technology. The survey covered Belgium, France, the UK, Italy, Switzerland, and the Federal Republic of Germany.

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CONTENTS

A SURVEY OF EUROPEAN ROBOTICS RESEARCH

1 INTRODUCTION

Background

Robots will profoundly affect the material and operations of the US Navy. Material will be influenced first--by advances in industrial robotics. For example, research is being done on the application of robot technology to ship and aircraft maintenance and repair, and to electronic component construction, testing, and repair. Using robots in these areas will make the acquisition and maintenance of the materials necessary for naval operations less expensive and more timely. Naval operations will be directly influenced somewhat later because of the more advanced concepts required to support robots with operational missions.

The US Navy has started several research efforts to explore the opportunities offered by robot technology, and more work is planned. However, financial resources are limited, so the emphasis of the research must be carefully chosen, and as much existing or developing technology as possible must be adapted.

Objective

This report describes the results of a 1981 survey to gather information about European robotics research that might be tailored to meet the Navy's needs; results of a November 1983 update will appear later. (For other recent information, see *ESN* 36-11, 36-12, 37-1, 37-3, 37-4, 37-5, 37-6, 37-7, 37-8, 37-9, 38-1, and 38-2.) The objectives of the study were: (1) to identify key research organizations and scientists, and (2) to determine the nature of the research and technology. The work was sponsored by the US Office of Naval Research, London, and the Naval Ocean Systems Center (San Diego, CA 92152).

Approach

Financial and time restrictions limited the scope of this survey to the activity of Belgium, France, the UK, Italy, Switzerland, and the Federal Republic of Germany (FRG). Representatives of 25 different groups at 24 different institutions in the six countries were contacted either directly or by telephone during the survey. The information in this report is based on on-site visits to 21 of the institutions and discussions with over 45 researchers. Table 1 lists the organizations visited; Table 2 shows the distribution of these organizations over academia, government, and industry.

The organizations shown in Table 1 were chosen from the results of a literature review conducted shortly before this survey began. The review included publication activity from the International Symposiums on Industrial Robotics (ISIR), the International Joint Conferences on Artificial Intelligence (IJCAI), and several related periodicals (e.g., *The Industrial Robot*, *IEEE Transactions on Automatic Control*, and *Pattern Analysis and Machine Intelligence*). Information from computer surveys of literature data bases such as IEE INSPEC (specifically, Computers and Control) and the Science Citation Index (SCI) was also integrated into this literature survey. In addition, several American robotics researchers were asked for recommendations about valuable contacts.

2 SURVEY RESULTS

Belgium

Only one active robotics research facility was visited in Belgium, the Katholieke Universiteit Leuven. Dr. Van Brussel headed the primary robotics research effort. Van Brussel's group consisted of two faculty and five graduate students. Their laboratory facilities included a Hewlett Packard minicomputer and a Cincinnati-Milacron T3 robot. This group was pursuing research in force sensing, active compliance, sensor-servoed robot control, and robot programming language development. They developed algorithms for active compliance, an actively compliant gripper, and a preliminary

Table 1

Robotics Tour Coverage, 1981

Country	Organization
Belgium	Katholieke Univ. Leuven, GTE Laboratories
France	CERT, INRIA, LAAS, LIMSI, LAM, IMAG, Univ. de Technologie de Compiègne
Italy	IEEM, LADSEB
Switzerland	Inst. de Microtechnique, DEC International
FRG	Inst. für Informatik III, IPA, ISW
UK	Cambridge Univ.; Heriot-Watt Univ.; Queen Mary College; Univ. College, London; Univ. of Edinburgh; MIRU; Univ. of Warwick; NEL; PERA

Table 2

Affiliations of Researchers

Country	Academics	Government	Industry
Belgium	1	---	1
France	3	4	1
Italy	1	1	---
Switzerland	1	---	1
FRG	2	1	---
UK	7	1	1

robot programming language. Their future interests included high-level robot programming languages, multiple-robot coordination, and high-speed robot control.

Federal Republic of Germany

The Institut für Informatik III at the Universität Karlsruhe housed a very large and active initiative in industrial robotics research. The group supporting this initiative was headed by Dr. Rembold, who also held one of only two applied research chairs at the Universität Karlsruhe. Dr. Rembold's group consisted of eight faculty, nine full-time research associates, and about eight graduate students. This group's facilities were widely distributed about the campus and included several microcomputers and minicomputers from various manufacturers, imaging hardware, and a Unimation PUMA 500 robot. Their research included robot vision, sensor-controlled robots, computer architecture and networking, robot programming languages, and robot software specification. They developed several passive vision systems, a laser vision system, a portable robot programming system, and a highly instrumented robot gripper. Their long-term and future directions included three-dimensional and gray scale vision, robot control from disparate sensor suites, robot programming languages, and high-speed computer architectures for robot vision and control.

The Institut für Produktionstechnik und Automatisierung (IPA) of Fraunhofer Gesellschaft in Stuttgart also had a very large effort in industrial robotics. The primary robotics research was in the IPA's automation section, which was headed by Dr. Schraft. This section consisted of the production systems and the measurement and control systems departments, which were of roughly equal size--about 20 engineers each. Only the production systems department was visited; it had 15 mechanical engineers, three electrical engineers, and two computer scientists. Most of these people were working for advanced degrees. IPA had extensive research facilities, including several robots from various manufacturers, both foreign and domestic; several vision systems of varying capabilities; several small computer systems for robot control; two VAX computer systems; and an Evans and Sutherland graphics system. The group was pursuing research in sensor-based robot control, automated vision for inspection, force and tactile sensors for grinding and deburring, flexible robot grippers, robot evaluation, prototype robot work-cell integration, and computer-aided robot installation planning. The group developed an extensive robot evaluation facility, several tactile and force sensors, several flexible robot grippers, control schemes for sensor-directed robot grinding and deburring, robot installation planning and simulation software, and several prototype robot work-cells for palletizing, assembly, inspection, and deburring.

The Institut für Steuerungstechnik der Werkzeugmaschinen und Fertigungseinrichtungen (ISW) of the Universität Stuttgart was also very active in industrial robotics research. Dr. Stute, an eminent German robotics researcher, headed ISW and emphasized robotics technology development. Most of the robotics research was concentrated in only one of ISW's three departments: the robotics and feedback control systems department, headed by Dr. Hesselbach. Hesselbach had about 30 full-time researchers and 20 full-time technicians in addition to the graduate students associated with the department. The ISW's facilities included several very large laboratories which contained many different automated machine tools. The robotics group shared these facilities with the other ISW research groups and had four robots of various types and several microcomputer and minicomputer systems used for robot control. This group was exploring several applications of sensor-controlled robots. The researchers were considering primarily welding and grinding applications. They had developed continuous path control techniques for weld grinding, sensors for weld surface characterization, and techniques for controlling a robot to grind cast-brass figures. The group was also working in state-variable descriptions and adaptive control theory and had developed techniques for controlling robots during high-speed precision maneuvers. In the long term, Hesselbach expected to do more work in high-speed robot control, force-controlled motion, workpiece shape modeling, and vision-controlled robot motion (see also *ESN* 37-6:207 [1983]).

<u>Switzerland</u>

The Institut de Microtechnique of the École Polytechnique Federale de Lausanne had a small but very productive robotics research group headed by Dr. Burckhardt. At the time of the survey, the robotics group had about 20 employees and was the largest of four groups making up the Institut de Microtechnique. The robotics group pursued research in manipulator design, hydraulic servo design, force and vision sensors, robot computer architecture, robot programming languages, and automated work cells which incorporated multiple cooperating robots. At the time of the visit, Dr. Burckhardt's group was designing two work cells, one for relay assembly and another for watch assembly and inspection. The group had developed basic guidelines for robot design, a multiple microcomputer system for simultaneous control of multiple cooperating sensors, force control algorithms, techniques for gray scale image interpretation, and several manipulators with both electrical and hydraulic actuators. Dr. Burckhardt expected future robot research in gray scale vision, object-oriented robot programming languages, integration of computer-aided-design data bases with robot planning and control, geometric modeling, and knowledge-based robot control.

Italy

The Polytecnico di Milano has one of the oldest and largest artificial intelligence and robotics research groups in Italy. At the time of the survey, the group was headed by Professor Marco Somalvico and consisted of three full-time faculty, one visiting faculty member, five research associates, two postdoctoral students, 10 graduate students, and over 50 undergraduates performing research projects for classes in advanced computer programming. This group's resources included a Univac 1100, a VAX 11/780, a PDP 11/34, an LSI 11/23, a MINC-11, several Hewlett Packard 6400 workstations, several microcomputers for robot control, an Olivetti SUPERSIGMA robot, a Unimation PUMA 500 robot, and hardware for image collection and processing. The research included work in natural language understanding, automated problem solving, automatic programming, expert systems, robot computer architecture, robot programming languages, sensor-based robot control, geometric modeling and image processing, and understanding. This group's efforts produced several natural-language understanding programs, three robot programming languages, several automatic problem-solving systems, many different subsystems for image processing and understanding, a multimicroprocessor computer for control of the SUPERSIGMA robot, techniques for robot error detection and recovery, and several expert systems for various purposes. Future research was expected to include the development of a robust problem-solving technique, implementation of advanced multiprocessor computers for robot control, development of a truly portable robot programming language, object modeling techniques, stereo image analysis, and gray level image processing techniques.

The Laboratorio per Ricerche de Dinamica dei Sistemi e di Bioingegneria (LADSEB) is a national institute for bioengineering and system dynamics research which had an active robotics research group headed by Dr. Pagello. At the time of the survey, the robotics research was supported by a PDP 11/34 and a MINC-11. This group worked with the researchers at the Polytecnico di Milano and shared their resources. Dr. Pagello's group was pursuing research in robot programming languages, geometric modeling, and robot actuator control. The group had developed a machine-independent robot programming environment such as that provided by ADA. Dr. Pagello's future research interests included integration of force and tactile sensor information with information from vision sensors, development of a parallel-processor computer architecture, and robot planning and problem solving (see also *ESN* 37-7:251 and 37-9:349 [1983], and 38-1:12 [1984]).

France

The Laboratoire d'Automatique de Montpellier (LAM) had an active robotics and biomechanics research group headed by Drs. Liegeois and Coiffet. The group was considering modeling and control of complex mechanical systems for three groups of applications: industrial robots, teleoperator systems, and prostheses. The teleoperator work is directed toward applications such as undersea oil exploration and nuclear reactor safety. The research on prostheses involved design and construction of a legged vehicle to improve the mobility of handicapped people. The primary thrust in robotics was related to modeling, design, and control of manipulators. The LAM robotics group had developed several computer programs to evaluate the performance of a robot for several different task demands and conditions. The group also had developed several techniques for automatic control of cable-driven manipulators. Other projects included workpiece location and identification using vision, and coordination of multiple robots for automated shoe manufacture. Future research areas for the LAM robotics group included enhanced robot modeling and design capabilities, visual image understanding, and robot control using force and vision information.

Dr. Latombe directed the artificial intelligence and robotics efforts at the Laboratoire d'Informatique et de Mathematiques Appliquees de Grenoble (IMAG). At the time of the survey he had four main projects: robot programming tools, automatic assembly, expert manufacturing planning, and robot vision. Latombe's researchers were working on a robot programming language called LM, as well as extensions LM-GEO for geometric modeling and LM-MAC for representing abstract data types. They also had developed an expert system which planned part-machining schedules and a program for automated assembly planning. The researchers were looking at basic gray scale vision and three-dimensional vision using a scanning laser. They had developed a scanning laser sensor design and were beginning implementation in November 1981. Dr. Latombe's future directions in robotics research included color image interpretation; multiple robot interaction issues (for both cooperative and antagonistic relationships); advanced robot programming languages, which included the capability to manipulate abstract data types; and piezoelectric tactile sensors.

The Department d'Études et de Recherches en Automatique (DERA) at the Centre d'Études et de Recherches de Toulouse was headed by Dr. Forestier. DERA was pursuing research in the applications of computer science and control systems for undersea, aeronautical, and space systems. The robotics research efforts at DERA were concentrated in two broad areas: flexible industrial automation and robots for space systems. The space systems research was just in the early feasibility-study phase at the time of the survey. The largest effort was in industrial automation. DERA scientists had developed computer control systems for a large industrial robot (80-kg capacity), a painting robot, and an arc welding robot. DERA also had been considering sensor guidance and safety issues of mobile factory robots. Future research directions included robot vision for inspection, mobile-robot pathfinding and obstacle avoidance, robot learning systems, lightweight manipulator design, and force-sensor design and control.

The Laboratoire d'Automatique et d'Analyse des Systemes (LAAS) has one of the oldest and largest robotics research groups in France. In 1981, the robotics research at LAAS was divided between two groups. One was exploring novel sensors and sensor data processing techniques, while the other was concentrating on robot logic and systems integration. Dr. Clot headed the sensor group, and Dr. Giralt headed the robot systems group. Giralt's group was one of the largest at LAAS and consisted of about 27 people. The group's research was in three main categories: robot control for assembly, robot perception, and robot decision making and planning. The robot control work involved modeling and control of manipulators, interpreting contact force information for workpiece characterization, sensor calibration and robot control, and control of precision robot movements. The perception research was primarily oriented toward visual image interpretation but also had considered interpretation of data from artificial skin and ultrasonic object sensors. The LAAS's vision researchers were exploring binary and gray scale vision for location and identification of overlapping objects. They also were developing techniques for abstracting three-dimensional information from two-dimensional imagery using structured light and input from a sensor such as a laser rangefinder. The automated reasoning researchers of LAAS were looking at knowledge-based object recognition, mobile-robot navigation, robot plan generation, decision making for automated assembly, computational complexity of decision-making algorithms, automated route planning, and production systems control. Giralt's group had two demonstration projects. One was an automated-assembly work cell employing multiple robots and sensor subsystems; it was the near-term focus for the group. The other demonstration vehicle was an advanced mobile robot designed to move through unknown indoor territory. This effort was more long-term and not aimed at any specific mission area. These demonstrations were considered the mortar between the different technological interests in the group.

The Université de Technologie de Compiègne, a relatively small technical school, had a very advanced robotics research group in its Applied Mathematics and Computer Science Department. The group was headed by Dr. Jean-Paul Barthes. Their laboratory was very well equipped with a VAX 11/780, a PDP 11/45, an Applicon CAD system, a Xerox word processor, several microcomputer workstations, and a Unimation PUMA 250 robot--all connected with an early implementation of Ethernet. This group was working on real-time vision processing, geometric data-base design, and automated systems integration. Dr. Barthes' group had developed an impressive gray-scale vision processor which could interface with many different imaging sensors and could process their data at frame transmission rate. This processor could perform a variety of functions on the sensor images, including filtering, image mixing, pattern analysis, and hierarchical image representation and storage. It removed the effects of variable illumination, flare, smoke, haze, and reflections. Dr. Barthes expected to move his group more in the direction of artificial intelligence technology and systems integration.

Mr. Osorio managed the robotics research activity at the Laboratoire d'Informatique pour la Mechanique et les Sciences de l'Ingenieur (LIMSI). Osorio's group had a well-organized and well-rounded robotics research program. Its three directions, listed from shortest term to longest term, were: manipulation for assembly, automatic visual inspection, and stand-alone robot work cells. At the time of the survey, Osorio's group employed 13 full-time researchers and technicians and three graduate students. They were looking specifically at construction of a Cartesian robot work cell and a gray scale vision system, and at the use of automatic speech recognition and synthesis techniques to improve human-robot communication. This group had designed and implemented techniques for stepper motor control which achieved significantly more than the manufacturers' rated performance from the motors. The researchers expected to implement a testbed for designing and testing control algorithms and for integrating the results from research in robot perception, communication, and decision making. Osorio also expected to begin research into the software layers which interfaced various robot programming languages with the operating systems which, in turn, supported the interfaces with robot sensors and actuators.

The robotics group at the Institut National de Recherche en Informatique et en Automatique (INRIA), headed by Mr. Germain, was exploring several areas of robot perception. This robotics group was small (approximately six full-time researchers) but had some exceptionally good ideas. At the time of the survey they were exploring perception using well-controlled laser illumination and image processing for assembly and inspection. They had developed a vision system which employed a computer-controlled laser for adverse optical environments, such as arc welding. This system moved the laser selectively around the scene and imaged that scene through two linear array cameras separated by a well-known distance. Clever laser-control algorithms greatly reduced the amount of the scene which needed to be scanned to gather sufficient information for robot control. They demonstrated the system by controlling a robot welding a cylinder. They expected to improve the system by using a solid-state laser device and by increasing the capability of the processor controlling the laser and collecting the image. (See also *ESN* 36-11:286 [1982]; 37-1:13-15, 37-3:97, 37-5:169, and 37-6:205 [1983].)

The UK

Dr. Davies and Mr. Ihnatowicz headed a robotics research effort at the Mechanical Engineering Department of University College, London. Dr. Davies was pursuing research into force-controlled hydraulic manipulators. He had developed a force sensor called a force revolver; this sensor had a simpler construction than the more widespread force-sensor designs (e.g., instrumented remote center compliance and Scheinman wrist sensor). He had also done some work in recognizing workpieces using force information. Ihnatowicz's interest in robotics began with kinetic sculpture design. He was looking at the design and control of advanced hydraulic manipulators and end effectors. He and Davies had constructed two- and three-degrees-of-freedom hydraulic manipulators. They planned to simplify the control of their future manipulators by using tapered cylinders and hydrodynamic bearings. They also intended to consider manipulator design for specific applications, such as underwater engineering.

Dr. Larcombe at the Computer Science Department of the University of Warwick was pursuing research into autonomous mobile robots. Larcombe's research group included about five graduate students. At the time of the survey, they were converting a jitney and a forklift from human control to complete computer control. Using several active acoustic sensors, the computer-controlled jitney could guide itself down a narrow corridor. Larcombe had significant experience in constructing several autonomous vehicles for a variety of purposes. One of the most interesting was a remote-controlled tracked platform used for explosive ordnance disposal; to it he added several computers and sensors for autonomous mobility. This robot used a scanning sonar for obstacle avoidance and dead reckoning for navigation; it had a large gripper with tactile jaw sensors. He expected to improve the mobility of his mobile factory robots by using simple vision sensors to locate and track overhead lighting fixtures and pathway striping.

Dr. Appleton was pursuing industrial robotics research at the University Engineering Department of Cambridge University. His research interests included machine interfacing, robot programming languages, software tools for automated manufacturing process design, and coordination of multiple robots for automated metalworking cells. Appleton had three graduate students working with him and had a well-equipped laboratory for a relatively small effort. The laboratory had an ASEA robot, several machines for automatic forging, and an LSI 11/03, which he had interfaced to the robot. Dr. Appleton's group had developed several tools which eased the programming of the ASEA robot. These tools permitted robot initialization, program downloading and uploading, and diagnostic interpretation from the LSI 11/03. Appleton intended to improve his software toolbox by adding programs which had knowledge about specific problem domains (e.g., forging, machining, and testing); this would help the part designer specify the manufacturing-process.

A very active robotics research group at the National Engineering Laboratory (NEL) was supported by the UK's Department of Industry (DOI). This support reflected the fact that the DOI saw automated manufacturing as essential to the development of British industry. Mr. McPherson headed the automated manufacturing engineering group at NEL.

The group was pursuing robot work cell integration and development of a real-time gray scale vision system. This group had developed an automated system for machining prismatic components, an automated assembly and test cell, a binary vision for part location and inspection, and an automatic turning cell which used a force-sensing chuck for machine control. The automated assembly and test cell employed a Unimation PUMA 600 to manufacture small electric motors. The vision system, called NELSON II, was implemented on a PDP 11/34 and could inspect as many as 20 parts per minute.

The Computer Science Department of Queen Mary College had a small research group headed by Dr. Bond, who had five graduate students. Their laboratory included a Unimation PUMA 600 robot, two mobile robot carts, several LSI 11/23 microcomputers, a speech understanding system, and Micro Consultants Ltd. digital video image processing equipment. The group was interested in robot vision, learning systems, and intelligent robot design. The group had built two mobile robots. The first was a small cart equipped with computer vision; it was used for perception and learning experiments. The second robot was equipped with two cable-controlled manipulators, infrared and acoustic proximity detectors, force sensors, and vision. This robot used a cooperating experts paradigm for reasoning and planning. Bond's group also had developed a technique for fast image processing using an array processor. The researchers were engaged in second-generation robot vision for industrial purposes, intermediate and high-level vision processing on an array processor, and speech control of robot systems. They were planning to integrate acoustic and infrared proximity sensors on the PUMA robot, to explore algorithms for graph matching and using motion parallax to infer three-dimensional structure with the array processor, and to investigate the opportunities offered by coupling industrial robots to existing speech-understanding systems.

The Production Engineering Research Association (PERA) was headed by an eminent robot researcher and advocate, Professor Heginbotham. He had transferred much technology developed while he was at the University of Nottingham into an environment where it got direct industry exposure. At PERA, he had formed a group of engineers who did robotics research, integrated prototype work cells for PERA subscribers, and advised subscribers concerning applications of advanced automation. PERA had a laboratory equipped with several commercially available feeders, pick-and-place devices, and computer-controlled robots. These facilities were used for demonstration of automation technology and on-site research. PERA had developed a modular computer-aided design system called [illegible]ACAM, a reasonably priced system which came complete with software for various manufacturing documentation and planning tasks. Two developments had been transferred from the University of Nottingham research and had been improved by PERA engineers: a sophisticated computer graphics simulation system, called SAMMIE, and a vision-controlled parts sorting and feeder control system. The latter system was a potential replacement for complicated, inflexible, and expensive mechanical parts feeders. PERA's research future depended on the demands of its subscriber companies and was, therefore, not widely discussed.

Heriot-Watt University is a small technical university; in 1981, it had an active group involved in unmanned submersible research. The group was headed by Dr. Russell, and he is supported by two other faculty, one post-doctoral student, three technicians, four graduate students, and about four undergraduate students. Their laboratory included a PDP 11/45 and several LSI 11/02 microcomputers as satellite workstations. This group had constructed two tethered submersibles called ANGUS 001 and ANGUS 002. Both vehicles had seen considerable operational use (in fact, ANGUS 001 was lost on such a mission). They had started building a third vehicle, which was to support free-swimming submersible research. The research was organized into three components: test-bed development, communications, and vehicle dynamics and control. ANGUS 002, the test bed, was a sophisticated vehicle equipped with a flux-gate compass, a television camera, and a short-baseline acoustic navigation system. ANGUS 003 was being developed to be used as a garage for a smaller free-swimming submersible. ANGUS 002 could communicate through either the tether or an acoustic link. Russell's control work involved designing and testing progressively more sophisticated control schemes on the ANGUS vehicles. His group had developed a computer simulation which permited benign initial control-scheme testing. Future directions included implementation of the ANGUS 003 concept, improvement of the vehicle simulation with better graphics and multiple interacting vehicle capabilities, improvement of the vehicle control by use of some techniques from artificial intelligence, and improvement of the acoustic communications link using data compression techniques.

The Department of Artificial Intelligence at the University of Edinburgh is one of the oldest and largest artificial intelligence research groups in the world. An interdisciplinary faculty was pursuing research into computer-aided education, mathematical reasoning, natural language processing, visual perception, and robotics. The visual perception group had people performing research into motion perception and intelligent robot vision. The primary faculty involved in robotics-related activities were Dr. Robin Popplestone and Patricia Ambler. They headed a large group of graduate students working on robot vision, programming languages, and robot control. The group had a very well developed laboratory with several robots of both hydraulic and electric actuation and several types of computer resources. The scientists also had robot research experience that extended back to 1969. Since then they had implemented several versions of a vision-controlled Cartesian robot named Freddy. They had developed a very robust program, the Versatile Assembly Program, which enabled Freddy to perform a complex assembly task. Their vision research in 1981 included efforts to integrate range information with two-dimensional vision; to integrate the use of vision into robot programming languages; to interpret color scene information; to linguistically represent visual objects; and to develop real-time, three-dimensional vision using automated reason techniques. This group had developed an advanced robot programming language called RAPT. RAPT described task objects and the working environment at an abstract level, and it permited specification of object manipulation in terms of the spatial relationships between the features of the task-object. The robot control work involved modeling the dynamics of the robot and the task environment. In the future, this group intended to pursue improvements to and extensions of RAPT, faster vision techniques, geometric reasoning, and scanning sonar imagery interpretation.

Another group at the University of Edinburgh was pursuing robotics research quite independently from the Department of Artificial Intelligence. The Machine Intelligence Research Unit (MIRU), was headed by a major contributor to machine intelligence for many years, Dr. Donald Michie. The bulk of the MIRU research was centered on image analysis. This work involved using an experimental cellular array computer called CLIP, which was developed and was being implemented by a group at University College, London. The MIRU had developed several programs for primitive vision which ran on CLIP; included were programs for filtering, edge detection, and blob labeling. Many of these algorithms had been implemented with good results. The MIRU was also exploring an industrial vision task in which a Unimation vision module was programmed to recognize chocolates on a conveyor belt. This vision system guided a manipulator to remove acceptable chocolates and place them in a box. Michie was developing a robotics teaching laboratory at the University of Edinburgh. The laboratory employed several tabletop robots connected to Apple II microcomputers. Michie felt that much of what students learned at these workstations would be transferable to industrial-robot applications. (See also *ESN* 36-12:328 [1982]; 37-2:261, 37-4:128 [1983].)

3 OBSERVATIONS FROM THE SURVEY

Several observations, as of 1981, can be abstracted from the survey interviews. These observations often are not directly related to the state of robotics research but are interesting reflections of the state of robotics technology. This chapter includes comments on robotics in industry, government's approach to robots, labor's perspective on robots, robotics education, and robotics research in Europe and the US.

Industry

Robots have invaded factories throughout Europe; Table 3 summarizes observations related to industrial producers and users of robots. Although the machines are used most often in automobile manufacturing, several other industries are beginning to explore more advanced states of automation. For example, the electronics and aviation industries are rapidly becoming major customers for robots. Robots are being

Table 3

Robots in European Industry, 1981

Country	Number of Builders	Function Examples	Application Examples
Belgium	0	Welding, passive handling, material removal	Automobiles, electrical components, recreational products
France	7	Passive and active handling, welding, assembly, finishing app., inspection, fastener handling	Electronics, electrical components, automobiles, aircraft and aerospace components
Italy	6	Welding, passive handling, finish app., inspection, assembly	Electronics, automobiles, business machines, electrical components
Switzerland	2	Passive handling, assembly	Watches, electrical components
FRG	8	Material removal, passive handling, assembly, welding, finish app., inspection	Automobiles, electrical components
UK	3	Material removal, welding, active and passive handling, inspection, finish app.	Automobiles, electrical components, aerospace components

applied to the manufacture of recreational products, watches, and business machines. Most robots are being used for welding, painting, and passive material handling. However, robots are also being used for material removal, surface finishing, inspection, assembly, and metalworking. Most of these appl'-cations use conventional preprogrammed robots, although force sensors are being used in a few cases. Sensors are slowly finding their way into the work place. The FRG and Italy lead the Europeans in the application of robots.

Of the countries visited, only Belgium had no robot equipment builders. (In this instance, robot equipment includes manipulators, control systems, end effectors, sensor systems, and other auxiliary equipment.) The FRG, Italy, and France appear to lead Europe in the number of robot equipment manufacturers; this is consistent with the observation that these countries are also the big users of robots. (Note, however, that the numbers in Table 3 represent only a sample of the industry and do not result from exhaustive study.) Robot development is hampered by the lack of venture capital available for new enterprises. In countries with significant interest in robotics, there are also large companies competing in foreign markets with Japan or the US. German, British, and Italian industries are aggressively pursuing the development and implementation of robots. The French have similar interests but are slowed somewhat by requirements to use predominantly French products. Swiss industry is also introducing robots, but with more caution than the other--more active--countries. Belgian industry is also employing advanced automation, but with considerable caution. These observations are summarized in Table 4.

Labor

In the labor forces of the European countries there appear to be two attitudes about industrial automation and, in particular, robots (Table 4). Labor in France and Italy has a positive attitude. In these countries, laborers enthusiastically welcome the introduction of automation into the work place. They see automation relieving them of arduous, repetitive, and hazardous jobs.

The second attitude is held by labor in countries such as the FRG, Belgium, and the UK. Laborers in these countries reluctantly accept the introduction of automation to their factories. They see automation as a necessary evil that takes away jobs but enables their factories to survive in the face of the automated competition of Japan and the US.

Government

Government participation in the automation of society varies widely in the six countries visited (Table 4). France and the UK have national initiatives to automate factories. In France, an advisory panel of industry representatives coordinates work by the academic institutions and the national laboratories. The UK pairs researchers from academia with those from industry so that academic research products can be put to practical use more quickly. At the time of the survey, Italy was developing an initiative similar to France's but had not appropriated the money. The FRG has very limited government involvement; much of the research is sponsored by industrial interests. However, government involvement in robotics in the FRG is increasing. Belgium's government also has limited involvement in robotics research, but is increasing its commitment. Only the Swiss government had failed to make any investment in robotics research; this is consistent with the observation that Switzerland has very limited academic activity in robotics research.

Education

All the countries visited had academics with interest in robotics research. These people represent the future for their respective countries, because people must be trained in robotics if there is to be increased use of automation. The only sources of technical training are the colleges and

Table 4

1981 Observations: Labor, Government, and Industry

Country	Labor	Government	Industry
Belgium	Accepts displacements to meet international competition	Supports robotics at low level and increasing	Cautious enthusiasm, no venture capital
France	Enthusiastically greets robotics advance; anticipates better conditions	1 year into national initiative to improve productivity	Implementing, but restricted to use of French goods
Italy	Greets robotics advance for better working conditions	$12 million funding programs introduced--fate uncertain	Very aggressive; implementing and building robots
Switzerland	No information	Funding situation poor	Limited interest but increasing
FRG	Accepts displacements to meet international competition	Limited government interest but increasing slowly	Aggressive interest; many implementing and building robots
UK	Accepts displacement to meet international competition	National initiative started pairing industry and academia	Active interest; new companies developing and old reorienting

universities. The figures in Table 5 are estimates of the number of institutions and professors involved in robotics research and education (i.e., no research associates or visiting professors included). Switzerland appears to be the poorest, while the UK appears the richest. The countries with the most active industry--the FRG, France, and Italy--all fall into the middle ground. Several schools in Europe have introduced robotics courses into their graduate and, less often, their undergraduate curricula. Only the FRG has integrated tracks of study which extend from undergraduate levels through graduate programs. In most of the countries, however, changing the curricula is a difficult, slow process.

The academic conditions are nearly as important as the raw numbers. These conditions determine how easily new academics can be attracted and retained. Hiring new professors is difficult in most of the countries visited. The ability to consult and supplement a professor's income could be the difference between retaining a valuable teacher and researcher and losing that person to industry, with its pay scales and fringe benefits. At the time of the survey, Belgium was in danger of losing to industry much of its academic expertise in robotics.

Europe Versus US

Tables 6 and 7 provide a crude comparison of attitudes toward robotics research in Europe and the US. Table 6 summarizes the perspectives on several issues related specifically to robotics research. The major research emphasis in Europe is much more application- and hardware-oriented than that in the US.

Table 5

European Robotics Education, 1981

Country	Number of Institutions	Number of Professors	Comments
Belgium	1	2	Curriculum change difficult and slow; opportunities only at grad. level; no consulting permitted; prof. loss possible
France	6	11	Robotics being integrated into grad. curriculum; considering undergrad. prep.; profs. stable; no consulting; hiring difficult
Italy	4	9	Robotics integrated into grad. curriculum; undergrad. prep. developing; profs. stable; hiring difficult; consulting encouraged
Switzerland	1	1	Robotics integrated into grad. curriculum; profs. stable; consulting permitted; hiring very difficult; unhealthy competition
FRG	4	10	Robotics integrated into undergrad. and grad. curricula; no consulting; hiring difficult; prof. loss possible
UK	10	15	Robotics available at grad. and undergrad. levels; consulting permitted; hiring difficult

Table 6

Robotics Research, 1981

Issue	Europe	US
Examples of major research interests	Programming languages, applied gray level vision, force sensing, robot design and modeling	Programming languages, three-dimensional vision, tactical sensing, decision making and planning
Research emphasis	Applications-oriented, balanced hardware and software interests	Basic research bias, predominantly; software interests
Military interests	Some	Active and growing rapidly
In-house industry R&D capabilities	Few large companies have them	Many large companies have them and more are developing

Table 7

Robot Development and Application, 1981

Issue	Europe	US
Venture capital	Nonexistent	Reasonably available
Robot application interest	Many large and a few medium companies purchasing robots	Many companies, large and small, purchasing robots
Robot acquisition strategy	Most countries are driving to produce and use own robots	Willingness to apply existing options prevails; large companies are buying foreign licenses when necessary
Perceived competition	US	Japan

European interest in robots for military applications is limited but increasing. The in-house research and development capabilities in industry reside almost exclusively in a few large companies, such as Fiat, Renault, and Volkswagen.

The development and application situations are compared in Table 7. Venture capital is nearly nonexistent in Europe. It is the large European companies that are interested in applications for robots, whereas many companies of different sizes in the US are beginning to use robots. Most of the companies in Europe--as well as their governments--are trying to produce and use their own robots. Industry in the US will use robots built by anyone that can supply the proper machine most economically. Interestingly, the US sees Japan as the major competitor, whereas the Europeans see the US as the major competitor.

4 CONCLUSIONS AND RECOMMENDATIONS

The primary robot research interests in Europe are robot programming languages, vision, force and tactile sensing, sensor-driven robot control, end-effector design, and robot computer architecture. Much of Europe's research activity in robotics is very application-oriented. Large manufacturing companies in Europe are doing much of the robotics research; many are designing and building their own robots. Europe has at least two national initiatives in robotics research, and others are in legislation. At the time of this survey (1981), robotics was rapidly growing in at least four of the six countries visited.

When research money must be used as efficiently as possible, very little duplication of effort can be tolerated. The Europeans have many capable researchers and well-equipped laboratories, and can produce much significant work. Awareness is only one step toward full cooperation. Interestingly, most of the European researchers seemed well aware of activity in the US and were, in some cases, building on work begun by US research groups. However, comparatively few researchers in the US seem aware of European research activity.