NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

FINAL PROJECT REPORT

NSF FORM 98A

PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING

PART I—PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
School of Civil Engineering Georgia Institute of Technology Atlanta, GA 30332	Structures and Build. System	CEE-8319498(E 20-603)
	4. Award Period From 9/1/84 To 2/28/87	5. Cumulative Award Amount 144,654

6. Project Title

" Robotics Feasibility in the Construction Industry "

PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

The main objective of this research was to develop a methodology to evaluate the potential of given construction processes and work tasks for robotization. The research was divided to five major tasks: 1) identification of high return operations, 2) analysis of standard technologies in selected operational areas, 3) extension of existing studies using videotype analysis, 4) study of existing and projected capabilities of robots, 5) microanalysis of motions associated with construction work tasks, and 6) evaluation of high return work tasks. During the first year of this research workshops with professionals were conducted to discuss potential construction operations for robotization and identify candidate processes for robotization. These workshops were held at Georgia Tech and summary information regarding three workshops is given in the NSF annual report. The purpose of convening these workshops was to discuss the concepts of automation and robotization with practitioners in the field and get feedback from industry concerning possible areas for automation. On going work was directed towards modeling and analysis of standard technologies using CYCLONE simulation techniques. The objective of this work was to study standard work sequences at the micro task level (i.e., work activities with duration of minutes or hours). An evaluation technique based on expert system was developed. The results of workshops on robotics was translated to production rules in order to establish an expert knowledge base. The final result of this model is a set of recommendations about a given construction process which describes whether it should be robotized. During the first phase of research seven technical papers published, three conference papers were presented, and two new graduate courses (Robotics in Construction Industry, and Expert Systems in Construction) were developed. Work to be accomplished in the coming (last) year of the grant will be consistent with activities described in the original schedule.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM: Check (✓)	Approx. Date
a. Abstracts of Theses	✓				
b. Publication Citations		✓			
c. Data on Scientific Collaborators		✓			
d. Information on Inventions	✓				
e. Technical Description of Project and Results		✓			
f. Other *(specify)*					

2. Principal Investigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
D. Halpin & R. Kangari/ G. Albright		3-2-86

NSF Form 98A (3-83) Supersedes All Previous Editions

Form Approved OMB No. 3145-0058

28 October 1985

Subject: Interim Progress Report

To: Gifford Albright

Division of Engineering Science

in Mech., Structures, and Materials Engineering

National Science Foundation

1. Name of Institution: Georgia Institute of Technology
2. Names of Principal Investigators: Daniel W. Halpin and Roozbeh Kangari
3. Grant No. CEE-8319498
4. Starting Date: 1 Setember 1984
5. Completion Date (Anticipated): 31 December 1986
6. Grant Title: Robotics Feasibility in the Construction Industry
7. Summary of Progress to Date:

A summary of progress based on the major items in the original proposal schedule is given in the sub-paragraphs below. In effect, all items scheduled for work during the first year have been commenced and satisfactory progress has been achieved.

7.1 Identification of High Return Operations

Workshops with professionals were conducted to discuss potential construction operations for robotization and identify candidate processes for robotization. These workshops were held at Georgia Tech and summary information regarding thee workshops is given in Appendix B. The purpose of convening these workshops was to discuss the concepts of automation and robotization with practitioners in the field and get feedback from industry concerning possible areas for automation.

The following classifications were used for characterization of candidate operations for automation and/or robotization:

(1) Dangerous, hazardous, and brainkilling operations

(2) Operations requiring a high level of precision

(3) Operations with high potential for production improvement

(4) Operations with potential for cost improvement

(5) Operations which utilize craft expertise which is vanishing

(6) Operations with a high potential for restructuring and innovation

Details regarding this preliminary survey of candidate operations are given in Reference 3, Appendix A.

Special attention was given to the identificaton of hazardous construction work tasks. Mr. Mendoza, a graduate research student, conducted a study to identify the major hazardous operations suitable for robotization. As part of this study, he developed an evaluation technique for establishing the level of hazard based on OSHA requirements and permissible exposure limits. Details of this study are presented in Reference 4, Appendix A.

7.2 Analysis of Standard Technologies

On going work is directed towards modeling and analysis of standard technologies using CYCLONE simulation techniques. The objective of this work is to study standard work sequences at the micro task level (i.e., work activities with duration of minutes or hours). Preliminary study of the concrete finishing process is contained in Ref. 3. This operation was selected since it is repetitive, requires precision, and can be boring. It has been robotized by several Japanese firms and this study will hopefully help identify what attracted researchers in Japan to develop prototypical equipment to handle this process. Several other operations to include rebar fabrication and rebar placement will be studies during Fall 1985. Tunneling and mining operations have been automated to a high degree and will also be modeled. Operations such as grinding, sand blasting, and bush hammering, as well as pavement breaking and similar demolition activities are being considered for study.

7.3 Extension of Existing Studies Using Video-Tape

Video tape studies have been made of several processes and evaluation of the work sequences involved is in progress. Processes which have been video-taped for the purpose of study include:

(1) Rock Quarrying

(2) Concrete block laying

(3) Steel Member Fabrication

(4) Steel Member Fabrication

(5) Pile Driving

(6) Pour in Place Concrete Barrier Wall Construction

(7) Reinforced Earth Retaining Wall Construction

Reduction of these processes to work task sequences for the purpose of identifying tasks with a high potential for automation/robotization is being accomplished.

7.4 Microanalysis of Motions

Functions of robot control vary according to the complexity of the work task involved in the process. A complex work task is viewed by the robot control as group of primitive tasks which need to be processed in order to finish the complex task. Figure 1 shows the relationship between these primitives and the corresponding level of robot sensory control.

The motions to be performed by a robot constitute a complex work task. High level vision sensors reduce complex tasks to a set of simple ones. These in turn are further broken down into elemental moves by intermediate vision processing. Elemental moves are the movements required by the different parts of the robot to process a given task.

These elemental moves are at a level subordinate to the work task as defined in Halpin and Woodhead (Reference 8, App. A) Methods-time measurement (MTM) concepts are being used to analyze these motions for high potential work tasks with high automation potential.

7.5 Development of Evaluation Technique for Ranking High Potential Work Tasks

An evaluation technique based on expert system will be developed. Preliminary study of various expert systems has already started. Utilization of microcomputer expert programs such as Insight Knowledge Systems Vers. 1 and 2 from Level Five Research, and the Deciding Factor, as well as other programs on mainframe (LISP) has been investigated.

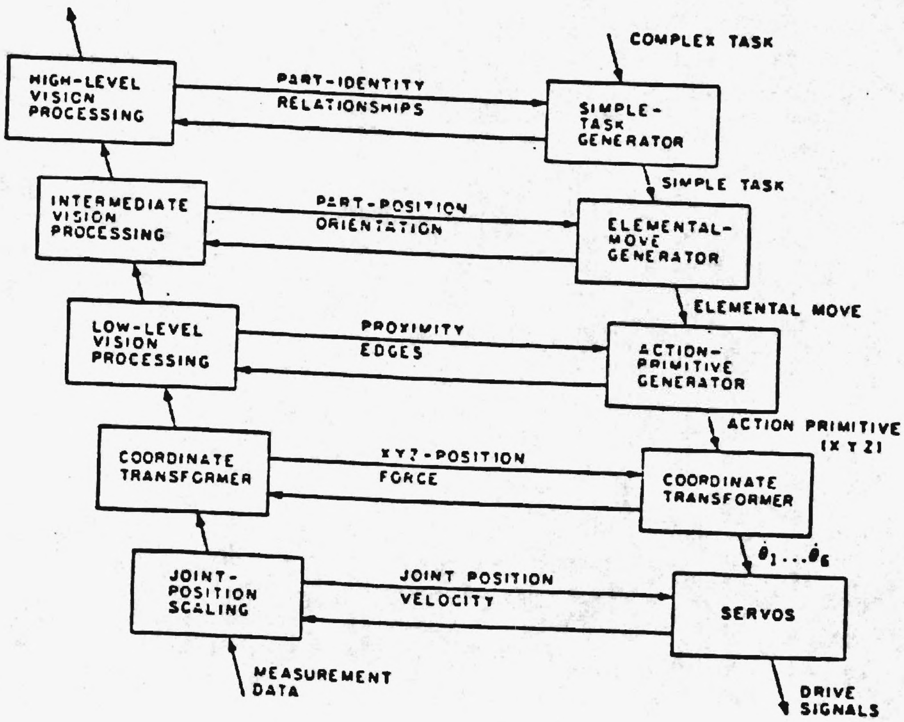

Figure 1. Relationship Between Primitive and Robot Control

The evaluation techniques based on these programs will combine the expertise of the parties involved in construction industry. The results of workshops on robotics will be translated to production rules in order to establish an expert knowledge base. Then, the results will be combined with an algorithmic model which estimates cost, profit return, and production of the operation. Utility value analysis will be considered whenever sufficient information is not available.

The final result of this model will be a set of recommendations about a given construction process which describes whether it should be robotized. A confidence level will be associated with each outcome. Necessary suggestions to improve or further automate a construction process will be provided. The methodology is designed to quantify qualitative judgements on the part of an expert group, and to combine that with the results of algorithmic model which estimates cost and production.

8. Current Problems and Favorable Developments

Work on this project will be impacted by the fact that the senior principal investigator has accepted the A.J. Clark Chair Professorship at the University of Maryland. This will result in coordination problems. It is recommended that the second year funding be moved to the University of Maryland. The attached second year budget has been modified to reflect moving the grant to Maryland. The amount of $64,654 will be expended at Georgia Tech. The remaining amount of $80,000 will be expended at Maryland.

9. Summary of Work to be Accomplished in the Subsequent Budget Period

Work to be accomplished in the coming (last) year of the grant will be consistent with activities described in the original schedule.

10. Other Pertinent Information

The revised budget with funding through the University of Maryland is given in Appendix D. All first year funds will be obligated by Georgia Tech prior to 31 December 1985. It is requested that second year funds be made available at Maryland on or before 1 December 1985. Figure 2 shows the research schedule.

Figure 2. Research Schedule

ACTIVITY	1984 S|O|N|D	1985 J|F|M|A|M|J|J|A|S|O|N|D	1986 J|F|M|A|M|J|J|A|S|O|N|D	1987 J|F|M
1) Literature and Background	XXXXXXX			
2 Identification of High Potential Construction Operations	XXXXX	XXXXXX		
3) Analysis of Standard Technologies (CYCLONE Modeling)		XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXX	
4) Extension of Existing Studies Using Video Tape Studies (Time Lapse, Motion Studies)		XXXXXXXXX		
5) Study of Existing and Projected Capabilities of Robots	XXX	XXXXXXXXXXXXXXXXXX		
6) Microanalysis of Motion Associated with Construction Task		XXXXXXXXXXXXXXX	XXXXX	
7) Development of an Expert Evaluation System Ranking High Potential Worktasks		XXXX	XXXXXXXXXXXXXXXXXXXXXX	
8) Publications and Conference Papers		XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX	
9) Quarterly Technical Reports	X	X X	X X X	
10) Annual Report		XX		
11) Preparation of Final Technical Report				XXXXX

Appendix A

Publications and Conference Presentations

TECHNICAL PUBLICATIONS:

1) "Robotics Feasibility in the Construction Industry," Proceedings of the 2nd Conference on Robotics in Construction at Carnegie-Mellon University, June 1985.

2) "Expert Construction Process Operation Systems and Robotics," Technical Report, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, March 1985.

3) "Robotization and Automation in Construction," Technical Report, School of Engineering, Georgia Institute of Technology, Atlanta, GA April 1985.

4) "General Application of Automated/Robotics to Hazardous Construction Work Tasks," M.S. Special Research Problem by E.J. Mendoza, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, March 1985.

5) "Automated Sensing for Control and Guidance in Construction," Technical Report, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, July 1985.

6) "Modeling Construction Robot Control," Technical Report, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, July 1985.

7) "Robotics in the Construction Industry: Union Perspective," M.S. Special Problem by C.J. Obetts, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, August 1985.

Other References

8) Halpin, D.W. and Woodhead, R.W., <u>Design of Construction and Process Operations</u>, John Wiley and Sons, Inc., Publishers, New York, 1976.

Conference Papers

1) "Robotics Feasibility in the Construction Industry", presented at the Robotics in Construction Conference at Carnegie-Mellon University on June 25, 1985.

2) "Results of Research on Robotics," presented and discussed at Group #4 (Robotics) Workshop supported by NSF for the development of new research direction at University of Illinois on May 1985.

3) Conference Presentation, "Robotics Applications in Construction," International Workshop on Automation of Mining Devices, Paris, France, May 21-22, 1985.

Appendix B

Summary Information
regarding Workshops

WORKSHOP ON ROBOTICS IN CONSTRUCTION

March 6, 1985

PARTICIPANTS:

- Peter Hickey, CM Rosser White
- Frank Speaks, CM HCB-Construction Comp.
- L. S. Riggs, Holder Construction Co.

- Prof. D. Halpin
- Leonard Bernold, Graduate Research Assistant
- Simon Abou-Rizk, GRA
- Noel Epelboim, GRA
- Sandeep Chawla, GRA
- Fady, Nakad, GRA

Repetitive construction processes or work tasks which:

1) are dangerous, hazardous, unpleasant, brainkilling
   - Precast panels, brick placement
   - Rubbing walls
   - Ditching
   - Stacking elevators
   - Tunneling
   - Sand Blasting
   - Grounding a floor slab
   - Insulation
   - Grinding
   - Chipping of concrete
   - Exterior curtain walls
   - Formwork
   - Exterior scaffolding
   - Panelization
   - Fire proofing
   - Structural work
   - Concrete work
   - Sand blasting
   - Bush hammering
   - Dry walls
   - Sewer maintenance
   - Insulation work

2) need high precision
   - Welding of conections (beam-column)
   - Brick work
   - Post tensioning
   - Form work

3) are critical for improving productivity
   - Delivery of materials
   - Concrete pouring
   - Rebar placement
   - Rebar fabrication
   - Steel decking
   - Stud decking

- Piping
- Concrete finishing (automated towering)
- Full penetration welds (beams)
- Fabrication of conducts (electric)
- Sprinkler pipes
- Plumbing
  Sanitary
  Sewerage
- Wall covering - painting
- Steel cages (slurry walls)
- Cladding fabrication
- Wire mesh
- Tiling

4) are not cost effective
- Drill piers
- Earth work
  Rock excavation
  Cut and Fill
- Cassion
- Brick building
- Curtain walls

5) require vanishing craftsmanship
- Tower crane operators
- Tiling
- Woodwork (doors etc.)

Potential areas for innovation

1) Product Innovation
- Precast panels
- Connections
- Brick laying (panelizing)
- Self leveling forms
- Preassembled window system into panels
- Super glue
- Softer concrete
- Formwork

2) Process Innovation
- Pile driving
- Combinaton of processes
- Exterior concrete insulation (sandwich)
- Deep foundation
- Cassion

3) Material Innovation
- Fiber concrete
- Plank construction
- Precast parking deck

WORKSHOP ON ROBOTICS IN CONSTRUCTION
APRIL 9, 1985

PARTICIPANTS:
Greg Bobbs, Superintendent in Building Construction
Grant Crate, CM Bellamy Brothers Inc.

Leonard Bernold, Research Assistant
Sandeep Chawla, Research Assistant
Noel Epelboim, Research Assistant
Harmon Jones, Research Assistant
Fady Nakad, Research Assistant

Repetitive construction processes or work tasks which:

1) are dangerous, hazardous, unpleasant, brainkilling.
   - pile driving
     Cable failure, pile falling, noise, dirty
   - caissons
     cave-ins, gases
   - coffer dams
     pressures, underwater control
   - demolition
     dust, noise, asbestos or disagreeable material
   - sewer lines
     cave-ins
   - painting (high girders)
   - welding (high rise steel)
   - post-tensioning
   - cleaning steel girders (in place)
   - shingling
   - bolted splices
   - decking
   - tying reinforcing
   - underwater work

2) need high precision.
   - sewer lines
   - curvature of curbs
   - segmental bridges
     automate processes at the casting yard
       i) self cleaning forms
       ii) movement of forming beds
   - panelizer
   - floor plan layout
   - reinforced earth
   - reinforced steel
   - bridge riding surface
     concrete finishing machine, power bull float
   - saw cutting

3) are critical for improving productivity.
   - tar roofing
   - material handling

eliminate double handling in small areas
- superstructure decking

4) require vanishing craftmanship
   - concrete finishers
   - carpenters
   - plastering

Potential areas for innovation:

1) Sensors - to monitor wear and tear on a piece of equipment to avoid hazards (e.g. crane cables and brakes), preventative maintenance (e.g. lubrication)

2) Monitors - where the operator cannot see what is going on

3) Controls - push buttons, voice actuated

4) Automatic leveling for fork lifts

5) Sonar on concrete screen to check minimum cover on embedded steel

6) Wind compensator for cranes

7) Tools
   - automated hammer to follow a chalk line
   - saw with automatic device for control, distance measurement
   - coring machine
   - automatic feed for welding rods
   - underwater work (remote control, video cameras, cutting tools)

WORKSHOPS ON ROBOTICS IN CONSTRUCTION
April 23, 1985

PARTICIPANTS:

Bob Angelo, V.P. Matterhorn Industries, Ltd.
P. Cabell Gregory, President American Equipment Co., Inc.
Jim Woods, Board Chairman Matterhorn Industries, Ltd.

Leonard Bernold, Research Assistant
Harmon Jones, Research Assistant
Fady Nakad, Research Assistant

Repetitive construction processes or work tasks which:

1) are dangerous, hazaadous, unpleasant, brainkilling.
   - Underground piping, ditching
   - Repetitive lifting by cranes
     operator boredom, human error, not thinking
   - Antiquated equipment (steel industry)
     blast furnaces
   - Material handling throughout all fabrication activities
   - Tower crane operation
     operator may not be able to see the end of the line
   - temporary riggings in steel erection
   - welding
   - steel fabrication
     fitters

2) Need high precision
   - layout
     anchor bolt, site plan
   - plumb the building
   - hand/eye coordination of heavy equipment operation
   - fine grading, grade contouring
   - drop (cutting waste) minimization
   - measuring pieces in fabrication

3) are critical for improving productivity
   - material handling
   - painting
   - siding insulation
   - scaffolding
   - welding decking sheets

4) require vanishing craftmanship
   - steel fabrication
     dirty work, skilled people find a better jobs
   - carpenters
   - insulation
   - fitters
     template fabrication for ductwork
     operators

Potential areas for innovation:

1) Equipment
   i) sensor to determine weight of crane load
   ii) control of crane boom angle under loading

2) Products
   i) inflatable forms
   ii) plastic fiber for concrete reinformcement
   iii) bonding materials, adhesives

3) Material
   i) new types of concrete
   ii) new rustproofing treatment of steel

Appendix C

Abstracts of Technical Reports

And Graduate Course Development

Robotics Feasibility in the Construction Industry

ABSTRACT

Many industries as construction are just beginning to realize the impact of full automation in their productivity, quality improvements, and safety. At the present time, robotics in construction industry are still on the stage of basic research. Major motivations for the application of robots in the construction industry are to increas productivity, improve worksite safety, enhance construction quality, and to perform superhuman tasks. The main objective of this paper is to explore the socio-economic aspects of the robotics feasibility in construction industry, and establish a basic foundation for future research. In general, the following questions will be addressed. What are the economic benefits of robotics? What are the impacts on labor? How can construction operations with high potentials for robotization be identified? Seven major variables affecting the feasibility of the robotics in construction industry are identified as: 1) cost effectiveness; 2) level of hazardous; 3) productivity; 4) quality improvement; 5) standardization of design and level of repetitiveness; 6) union resistance; and 7) technologically feasible. Each of the above areas are explored. To models are presented for the robotics feasibility in the construction industry: 1) simplified management decision model; and 2) utility decision model. The ultimate output of these models provide an index which indicates the level of automation.

General Application of Automation/Robotics
to Hazardous Construction Work Tasks

ABSTRACT

This report provides information on the hazardous conditions that appear in certain construction work tasks, and presents an evaluation method for the hazardous conditions. A classification of hazardous construction operations is presented using data from the OSHA. The report provides different kinds of work task diagrams that can help the contractor into making an evaluation of these work tasks to consider robots. The approach taken to establish this rationale is first to introduce a series of diagrams that will show a "step-by-step" procedure for accomplishing each work task. Second, it will indicate where and how a hazardous condition can occur and how it can be measured, using the special instruments and evaluation criteria. With these sources of information, the safety professional can analyze the work conditions that are present at a job site. If the work conditions are hazardous to the workers, he can replace them with a robot or an automated remote control machine, otherwise, if there is no hazard involved, the work task can be finished without any interruption.

Expert Construction Process Operation Systems
and Robotics

ABSTRACT

A methodology for building expert construction operation design system for the automation and robotization of construction processes are presented. The model allow the engineers to design a construction process operation as if the most construction field expert was providing advice and guidance based on long experience. The proposed expert design system can also serve as training and teaching tools, providing the students a synthetic experience in dealing with design of ill-defined cyclic construction operations which are suitable for robotization.

During the next decade, the field of expert systems will have an impact on all areas of construction field where knowledge provides the power for solving construction engineering and management problems. The first and most obvious will be the development of construction knowledge base which converts the professional construction knowledge into an efficient and productive industrial field. The second benefit is that the expert construction systems will catalyze a global effort to collect, codify, exchange, and exploit applicable forms of construction engineering and management knowledge. The third benefit is that the basic capabilities of the developed expert design model can be extended to provide interfaces to the sensors and consequently the development of real robots in construction industry.

Robotization and Automation in Construction

ABSTRACT

This report addresses the problem of mobility of robots and the limitations in general, develops a selection criteria for identifying potential construction processes, and describes a concrete finishing process as an example for modeling and analysis using CYCLONE techniques. Various mobility systems and navigations such as: 1) remote controlled vehicles (RCV); 2) servo-controlled vehicles (SC); 3) autonomous computer controlled vehicles (CCV); and 4) semi-autonomous computer controlled vehicles (SCCV) are presented. The following major factors were considered: environmental protection, position dtermination; path determination; machine-machine communication; man-machine communication; dynamic control and steering architecture. A selection criteria for identifying potential construction processes for robotization and automation is developed. The model considers the following major factors: hazard, repetitiveness; quality; productivity; and mobility. This report also summarizes the results of workshops on robotics in construction held at Georgia Tech. The workshops identified the high potential construction operations which are suitable for robotization. The potential areas for innovation are discussed and explored.

Modeling Construction Robot Control

ABSTRACT

CYCLONE technique is used to model construction processes for robotization and automation. The report describes how modeling can be used to study robot control. Robot control represents a complex system and therefore requires a multi level or hierarchical approach to study its structure. Systems theory and cybernetics offer excellent tools to study dynamic systems. Modeling the robot control on the other hand allows to abstract from a physical system but still depending on a full understanding of what is really happening. A robot represents a self correcting system which is able to handle inconsistencies in its environment. It performs the desired task based upon the input data which is fed into it. The control unit processes the information about the work task and about the rules for performing this task. These rules and work task information is known to the robot prior to the start of the operation. Input conditions and Output results are checked before and after each cycle of process. They are compared in the controller against the knowledge base stored in it. If while matching these results against previously stored knowledge, any variations from the desired track of operation are detected, corresponding instructions are issued to correct that. Process is initialized by the controller in the beginning. Initialization may involve checking the location etc. of the process. Prior to each cycle, the availability of resources e.g. Concrete, Bricks etc. for a given work task is checked. The report also describes the hierarchical levels in construction and senor control systems.

Automated Sensing for Control and Guidance
in Construction

ABSTRACT

The instrumentation of human senses are not the only goals of sensor technology. It also tries to take advantage of other physical phenomenon, e.g. magnetism. There are basically two classes of sensors, the status and the analog systems. From a historical point of view, they can be divided into three categories, basic, advanced and most advanced or high-tech sensors. Each category is described and its implementation in construction industry is discussed. Variety of new sensors used by several construction equipment manufacturers, e.g. Komatsu, are presented. The sensors are used not only for monitoring purpose but also t achieve semi-automation, higher accuracy and lower fuel consumption through optimal movement guidance. Sensors for increased safety are presented, human errors and misconduct are causing a large amount of accidents, even on the construction sites. Sensors could assist and monitor human actions and interfere according to predefined schemes. Example for equipment maintenance sensors are presented. Sensors are used for preventive maintenance of equipment by observing crucial machine parts, and operating conditions. Laser tracking systems are used to increase quality in several areas as vertical formworks, or tunnel machine control. The report also discusses the use of sensors for monitoring and updating construction material flow.

Robotics in the Construction Industry:
Union Perspective

ABSTRACT

At this time, the construction labor organizations are nominally interested in the potential use of robotics in the construction industry. This is fostered by the belief that the construction environment is too random and demanding to allow robots to function effectively for the foreseeable future. Thus, no formal policy has been developed towards robotization, and the cavalier statement that "the unions will not stand in the way of progress or the new technology to achieve this progress" can be made easily. However, the labor organizations need look no further than the recent experiences of the automobile and steel industry labor unions to achieve the needed hindsight with regard to what happens to labor when a shortsighted approach is taken toward robotic applications. The old saw - "an ounce of prevention is worth a pound of cure" - can act as a valid red flag which can alert the construction unions to develop guidelines today to accommodate a smooth transit to robotics in the ocnstruction industry and save their union members from future turmoil in their working lives. This report presents the results of interview with middle and upper levels of union management on the subject of robots in construction. The report also proposes a draft guidelines with regard to robotics use in the construction industry.

Robotics and Automated Equipment
in Construction Industry

Course Objectives

The potential for using robotics in the general field of construction is of great interest and concern to several groups. The development of construction robotics in Europe and Japan are far ahead of the United States. Japanese are making extensive use of robotics on the construction site. Even in small countries such as Israel there have been significant developments in the use of robotics in construction. The development of the Robotics in Construction course is not only a concern to graduate students but also practitioners in the private sector, university and other research groups and government officials. This course provides students with the knowledge necessary in the application of robots in construction industry. The second objective is to prepare graduate students for research funded by NSF.

Subtopic Covered

This course covers the following material: classification and definition of robots; mobility system, motor system, vision system, manipulators, economical aspects and justifications, productivity impacts, social aspects, principles of robotics in construction industry, robotics in hazardous construction operations, robotics in underground and underwater operations, and laser control system.

Textbook

The following papers presented at the Conference on Robotics in Construction, at Carnegie-Mellon University, 1984, were used as a textbook:

Paulson, B.C., Automated Control and Robotics for Heavy Construction

Shimomura, Y., Tunneling by Robots

Fenves, S.J., and Rehak, D.R., Role of Expert Systems in Construction Robots

Warszawski, A., Application of Robots to Building Construction

Crowley, J.L., Dynamic World Modeling and Navigation for an Intelligent Mobile Platform

Kano, N., and Tamura, Y., A New Management Tool for Robotized Construction Projects

Manninen, M., Supervisory Control of Large-Scaled Manipulators in Severe Environments

Appendix D

Revised Budget for Second Year

PPENDIX V

SUMMARY PROPOSAL BUDGET At University of Maryland

OMB No. 3145-0058
Exp. Date 12/31/85

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS)	
	Proposed	Granted
AWARD NO.		

RGANIZATION
University of Maryland

RINCIPAL INVESTIGATOR/PROJECT DIRECTOR
Daniel W. Halpin

SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	NSF FUNDED PERSON-MOS. CAL.	ACAD	SUMR	FUNDS REQUESTED BY PROPOSER	FUNDS GRANTED BY NSF (IF DIFFERENT)
~~Daniel Halpin~~			2	$ 16,000	$
( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
( ) TOTAL SENIOR PERSONNEL (1-5)					
OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
( ) POST DOCTORAL ASSOCIATES					
( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
(2) GRADUATE STUDENTS				12,500	
( ) UNDERGRADUATE STUDENTS					
( ) SECRETARIAL-CLERICAL					
( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				28,500	
FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				5,985.60	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				34,485.60	
PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000:)					
TOTAL PERMANENT EQUIPMENT					
TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				2,500	
2. FOREIGN					
PARTICIPANT SUPPORT COSTS					
1. STIPENDS $					
2. TRAVEL					
3. SUBSISTENCE					
4. OTHER					
TOTAL PARTICIPANT COSTS					
OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,000	
2. PUBLICATION COSTS/PAGE CHARGES				2,000	
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS R. Kangari at Georgia Tech				17,568.36	
6. OTHER				3,000	
TOTAL OTHER DIRECT COSTS				57,553.96	
TOTAL DIRECT COSTS (A THROUGH G)					
INDIRECT COSTS (SPECIFY)					
TOTAL INDIRECT COSTS				22,446.04	
TOTAL DIRECT AND INDIRECT COSTS (H + I)				80,000.00	
RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS GPM 252 AND 253)					
AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 80,000.00	$

/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Daniel W. Halpin	11/5/85	INDIRECT COST RATE VERIFICATION		
IST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - DGC Program

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPM 233)