NISTIR 88-4006

Assessment of Robotics for Improved Building Operations and Maintenance

Bal M. Mahajan[1], John M. Evans[2], and James E. Hill[1]

[1]U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
(Formerly National Bureau of Standards)
Center for Building Technology
Building Environment Division
Gaithersburg, MD 20899

[2]Transitions Research Corporation
15 Great Pasture Road
Danbury, CT 06801

November 1988

Prepared for
General Services Administration
Public Buildings Service
Washington, DC 20405

NISTIR 88-4006

Assessment of Robotics for Improved Building Operations and Maintenance

Bal M. Mahajan[1], John M. Evans[2], and James E. Hill[1]

[1]U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
(Formerly National Bureau of Standards)
Center for Building Technology
Building Environment Division
Gaithersburg, MD 20899

[2]Transitions Research Corporation
15 Great Pasture Road
Danbury, CT 06801

November 1988

National Bureau of Standards became the National Institute of Standards and Technology on August 23, 1988, when the Omnibus Trade and Competitiveness Act was signed. NIST retains all NBS functions. Its new programs will encourage improved use of technology by U.S. industry.

Prepared for
General Services Administration
Public Buildings Service
Washington, DC 20405

U.S. DEPARTMENT OF COMMERCE
C. William Verity, Secretary

Ernest Ambler, Acting Under Secretary for Technology

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Raymond G. Kammer, Acting Director

EXECUTIVE SUMMARY

Mobile robots for application in the service sector of the economy are under development in the United States, in Europe, and in Japan. Mail delivery robots are now available. Cleaning and security are two areas of intense product development. New products will appear in the near future that will impact building operation and maintenance.

The General Services Administration has responsibility for maintenance and operation of federal government buildings. In order to insure that new technologies that can reduce costs and improve the quality of services can be adopted in the future, GSA desires to insure that new buildings are built or procured that will be compatible with robotic products. The National Institute of Standards and Technology (NIST) is providing technical support to GSA in this area. This report provides an evaluation of products and development projects relevant to building operations and maintenance.

Floor cleaning, security, and mail delivery represent current or near term opportunities for robotic applications. Office cleaning, window cleaning, bathroom cleaning, lawn mowing, and miscellaneous material handling are other robotic tasks in the future.

Economic payback from these new technologies varies from one to three years at the current or predicted product pricing levels. Substantial savings in the cost of building operations and maintenance would be possible in the 1990's.

Recommendations are made that:

1. **GSA establish a technology monitoring and testing program** to fully evaluate the implications concerning the application of service robots in federal buildings.

2. **GSA develop education and training programs** to introduce robotic technologies to building occupants, machine operators, and supervisors responsible for building operations and maintenance.

ABSTRACT

This report provides a state-of-the-art survey of robotic technology useful for building operations and maintenance. Floor cleaning, mail delivery, security, and storage facility operations represent current and near term opportunities for robotic applications. Likely future applications may include: bathroom, office and window cleaning; lawn mowing; trash handling; wall painting; and miscellaneous material handling. Potential barriers to the use of robotics within buildings are identified. Amendments to the GSA Handbook on "Quality Standards for Design and Construction" to accommodate the use of service robots in federal buildings are suggested. The suggested amendments are not exhaustive, and as our knowledge base expands these should be refined and augmented.

KEY WORDS: Barrier; building; floor; cleaning; delivery; mail; maintenance; operation; robotic; security; service.

PREFACE

The names of private corporations (domestic or foreign) mentioned in this report are used primarily to identify those organizations that are known to be involved with service robots; these mentions do not represent an endorsement by NIST or GSA of the organizations or their products. The omission of other organizations and their products from this report does not imply that NIST or GSA found those to be less suitable.

TABLE OF CONTENTS

1. INTRODUCTION

The use of robotics in the factory environment has exploded within the past decade with over 30,000 robots in use in the United States and more than 200,000 worldwide. The extensive use is largely due to the ability of robotics to increase productivity in manufacturing. The use of robotics outside the factory in areas such as construction and large scale assembly has also been receiving considerable attention.

One significant area of new interest that has started to receive attention is in service robotics, that is, mobile robots for application in the service sector of the economy. Service robotic devices that are either currently available or under development include: robots to assist the handicapped, robots as educational aids, robots as hospital aids, and robots to perform many building operations and maintenance tasks. Building operation and maintenance tasks that are potential candidate for automation include: floor cleaning, mail delivery, security, painting, window cleaning, office and bathroom cleaning, miscellaneous material handling, and lawn mowing.

The General Services Adminstration (GSA), through the Public Buildings Service (PBS), is responsible for the operation and maintenance of buildings owned by the federal government which total over 240 million occupiable square feet. In addition, PBS is responsible for the design, development, and procurement of building space with an annual construction budget typically in excess of $400 millions [1]. Often, it is through this construction activity that the new technologies are applied to establish functional merits and economic return.

With a building operation and maintenance budget of about $537 millions annually [1], PBS is, interested in new technologies that would reduce the costs or that would improve the quality of services for the occupants of the federal buildings. In order to insure that the new and retrofitted federal buildings can easily accommodate the desirable new technologies, GSA is particularly interested in assessing the functional needs of emerging service robotics.

One of the tasks undertaken in 1987 by National Institute of Standards and Technology (NIST) in support of GSA was the assessment of robotics for improved building operations and maintenance. The objective of this NIST project is to complete an assessment of the potential for robotics use in GSA buildings and to develop guidelines for the application of robotic devices in federal buildings.

This report presents a state-of-the-art survey of robotic technology, examines the potential barriers to the use of service robots in GSA buildings, and suggests guidelines for amending the GSA Handbook, "Facility Standards for the Public Buildings Service PBS P 3430.1A ," to accommodate robotic technology.

2. PROBLEM SIGNIFICANCE

PBS/GSA operates and maintains thousands of buildings amassing about a quarter billion square feet of floor space. With this inventory, the yearly operating expense for these buildings is about three quarter of a billion dollars. For example, the average expense for commercial floor cleaning alone can range between $0.60 - $1.00 per square foot per year. The FY-1987 GSA Funds for Real Property Operations [2], broken down into the catagories of expenditures, is shown in Table 1. Table 2 shows the building operations components of this budget, along with the potentially applicable automation or robotic technologies. Clearly, any possible use of robotics to improve service or reduce operating cost would be valuable to GSA and to the national economy.

Table 1: Federal Buildings Funds For Real Property Operations
FY 1987 ANNUAL PLAN
($Million)

Buildings Management		572
Cleaning	173	
Maintenance	121	
Utilities/Fuel	199	
Other Services	20	
Admin. Support	59	
Protection		58
Admin. Support	10	
All Other	48	
Contracts		10
Real Estate		28
RP Pol. & Oversight		2
Commissioner & Other		73
TOTAL		743

Table 2: Cost of Real Property Operations and Applicable Automation

Operation Category	Cost($million)	Applicable Automation
1. Utilities/Fuel	199	Design, Retrofit, Process Control.
2. Cleaning	173	Service Robotics.
3. Maintenance	121	Expert Monitoring Systems,Robotics.
4. Protection	48	Robotics, Security Systems.

The building operation category with the largest expense, utilities/fuel, has received a great deal of attention since 1973 through energy management. Effective cost controls through energy efficient designs of new buildings and retrofit of old buildings are well understood. The building operation category with the second largest expenditure is cleaning. This area is receiving a great deal of attention in developing robotic machines for a variety of cleaning tasks as will be discussed later.

Maintenance, the third largest expenditure class, consists of a large number of different work actions that are difficult to consider in terms of a single class of automation. Designing for minimum maintenance in terms of structures, components, and materials may be the best means of cost reduction in this area. Although, the use of expert systems to monitor building components and systems has recently been receiving some attention. This use of expert systems, currently, is oriented toward administrative controls such as analyzing faults, and scheduling preventive maintenance.

Service robots may play a role in the future, particularly in such areas as grounds maintenance. Lawn mowing automation is an area of interest to some companies and university research groups. It has been speculated in the trade press that product liability is a strong deterrent in this area.

Protection, the fourth category of building operations, is a potential candidate for robotic use. Traditionally, protection services are provided by hard-wired security systems with perimeter interlocks and interior motion detection sensors and/or by monitoring systems with multiple sensors and television cameras. A recent innovation is the concept of a robot security guard which would provide a mobile sensor platform with a radio link back to a guard station.

The second and fourth catagories, the so called "mops and cops" building operations, represent building operation functions with the largest expenses. Not surprisingly, "mops and cops" is the focus of commercial mobile robot development. The combination of market opportunity and technology development is creating a new industry of service robots. Recent articles published in national journals and newspapers [3 - 5] provide an overview on this trend.

3 GLOSSARY OF TERMS.

A comprehensive glossary of terms for robotics is available in reference 6. For this overview report the following definitions are appropriate.

Actuator: A motor or transducer which converts electrical, hydraulic, or pneumatic energy to effect motion of a robot.

Artificial Intelligence (AI): The ability of a device to perform functions that are normally associated with the human intelligence, such as reasoning, planning, problem solving, pattern recognition, perception, understanding, and learning.

Automation: The automatic operation or control of a process, equipment or a system. Or the technique of making a process automatic, self moving, or self-controlling.

Bang-Bang Control: A binary control system which rapidly changes from one mode or state to the other (in motion systems, this applies to direction only).

Beacon: Anything that warns or guides, usually categorized as either active or passive in function. For example, a radio transmitter or a flickering light is an active beacon, and a reflective paint or tap is a passive beacon.

Dead reckoning: A navigational technique where the position of a mobile robot (or any vehicle) is estimated by sensors without any feedback from actual ground truth information or where the position estimate is based on interference and guesswork.

Encoder: An electromechanical device for sensing the rotation of a shaft or a wheel and converting the angular movement to a digital signal.

Feedback: A signal derived from the output which is used to drive the control actuator.

Point-to-point control: A control scheme whereby the inputs or commands specify only a limited number of points along a desired path of motion. The control system determines the intervening path segment.

Programmable: Capable of being instructed to operate in a specified manner or to perform specified tasks.

Programming Language: A computer language especially designed for writing programs for controlling robots.

Proximity Sensor: A device which senses that an object is close and/or measures the distance between a robot and an object.

Ranging: A scheme to calculate the distance between a sensor and an object for the purpose of figuring out the location of a robot with respect to the object. Or a scheme for mapping the position of a robot with respect to its surrounding by using signals from a sensor. Depending on the sensors used, the process may be called "**Infrared ranging**", "**Laser ranging**" or "**Ultrasonic ranging**".

Robot: A programable mechanical device which can be programmed to perform some task of manipulation or locomotion under automatic control.

Sensor: A transducer whose input is a physical phenomenon and whose output is a quantitative measure of that physical phenomenon.

Servo-mechanism or servo: A feedback system that consists of a sensing element, an amplifier, and a servomotor, and is used in the automatic control of a robot or mechanical device.

Teach: To program a robot by guiding it through a motion pattern which is recorded for subsequent automatic action.

Teach Mode: A mode of operation of a robot during which the robot is taught to carry out a desired motion pattern.

Transducer: A device which converts one form of energy into another form of energy.

Vision or Machine vision: The ability of a machine (robot) to automatically acquire, analyze, and interpret image data. Machine vision enables a robot to recognize shapes, sizes, distances, and sometime colors, and to take action on the basis of these inputs. Monocular vision means that the image data is acquired with one camera (sensor); binocular vision means that the image data is acquired by two cameras to produce stereo effects to increase depth perception.

4. HISTORY AND TRENDS OF ROBOTICS TECHNOLOGY DEVELOPMENT

Automation is the automatic operation or control of a process, equipment or a system. Robots are a kind of automation. A robot is a mechanical device which can be programmed to perform some task of manipulation or locomotion under automatic control. Robotic technology refers to the design and application of robots.

A perspective on the application of robotics in services can be gained by examining the history and technology of industrial and service robots. Basically, many of the component technologies of industrial robots are derived from Artificial Intelligence (AI) research, particularly vision and programming languages. Over the past three decades since the first industrial robot was built, the trend until recently has been toward greater intelligence in the machine controls. The advent of computer integrated manufacturing systems in the 1980's has changed that trend. Now, the application of AI in manufacturing is at the system level rather than the process or device level, thus individual industrial robots are becoming less intelligent. On a different front, new applications of robotics in the service sector of the economy emphasize mobility and autonomy and demand increasing use of AI.

4.1 INDUSTRIAL ROBOTS

Industrial robots represent an annual market in excess of $400 million in the U.S. and $1 billion worldwide. There is a tremendous range of products available from all of the industrialized Western countries. Some of the current successful applications of industrial robots are listed in Table 3.

Table 3: Some Successful Applications of Industrial Robots

Arc Welding	Heat Treatment	Plastic Molding
Batch Assembly	Investment Casting	Order Picking
Conveyor Transfer	Inspection	Spot Welding
Die Casting	Machine Loading	Stamping
Fettling	Packaging	Textile Processing
Forging	Paint Spraying	Wire Harness Manufacturing
Glass Handling	Palletizing	

These systems have historically played a significant role in the industrial field and have found wide application in Japan. The simplest industrial robots have a "bang-bang" or a limited sequence controls in which the position of each axis is controlled by mechanical stops.

Most industrial robots have servo-mechanisms (servos) to control each axis. These servo based point-to-point control systems allow desired positioning of each axis independently. The operator leads the robot through a desired series of points, recording the position of each joint at each point; and during playback, the joints are moved to the desired location by the servos.

To guide robots with rotary joints, computers have been added to the control system to perform coordinate transformations so that the robots can be directed to move in cartesian coordinates that are frame-referenced to the work space or to the work piece. For robots to be applied in assembly, in process applications requiring sensory feedback, and in low volume batch manufacturing applications, a sophisticated control system with a higher level language is usually needed. Most robot programming languages today derive from AI work of the late sixties and early seventies.

4.2 SERVICE ROBOTS

In recent years, a great deal of interest has been evidenced by researchers and entrepreneurs in new applications of robotics outside of the bounds of manufacturing. Mobile robots for application in the service sector of the economy are emerging rapidly. Some of these are listed in Table 4.

Table 4: Some Areas Of Service Robot Applications

Toys	Animal Husbandry	Lawn Mowing
Hobbies	Fast Food Service	Mail Delivery
Education	Floor Cleaning	Nuclear Maintenance
Construction	Gasoline Dispensing	Storage Facility Operations
Military	Geriatric Aides	Surgical Assistance
Security	Household Aides	Undersea Aides
Space	Hospital Aides	Window Cleaning

While some of these may seem more science fiction than engineering, serious projects have been undertaken in each area, and substantial sums of money are being spent. The Defense Advanced Research Projects Agency of the Department of Defence (DOD) has spent $55 million on autonomous vehicle research, the Army's spending for robotics is expected to reach $500 million by 1990, and Congress has dictated that 10% of the Space Station budget, or about $2 billion, is to be spent on automation and robotics technology.

One of the common threads in many of the above mentioned applications is the appearance of mobility. Attacking the general problem of mobility, researchers have found that the key problems revolve around the issues of sensing and modeling the robot's surroundings. Various sensing systems have been used for recognizing landmarks in the environment of the robot to register the position of the robot with respect to its surroundings. Sensors for navigation include infrared ranging, laser ranging, ultrasonic ranging, machine vision, active and passive beacons, and various dead reckoning schemes including wheel encoders and gyroscopes. Once the robot can navigate, it can then carry out its assigned tasks whether those be security monitoring or cleaning a floor. A brief discussion of robotic navigation technology is presented in Appendix B.

The interesting trend in these service or non-industrial applications is that the robot is an independent, autonomous unit that will require increasing intelligence to carry out more difficult applications rather than the reduced intelligence as in the manufacturing case. Indeed, robotics research at many AI labs across the country is focused on service applications with underlying technical issues of mobility and navigation.

5. STATUS OF SERVICE ROBOTS

This section briefly describes service robots applicable to building operations that have been introduced as products or that are under development and are expected to become products in the near future. The descriptions also include the navigational systems/schemes used to control the mobility of the product. Available brochures and other relevant material for some of the products are included in Appendix C.

5.1 FLOOR CLEANING ROBOTS

Floor cleaning has received more attention than any other area on commercial service robot development in the past several years. Tile flooring are of the great interest, since cleaning operations often include daily sweeping, dry mop, damp mop, buff, and dry mop. Within office buildings, however, an increasing application of floor finish is carpet. Here again, there is a frequent cleaning requirement. Carpet can be vacuumed daily in high traffic areas and on a discretionary and weekly basis in offices and low traffic areas.

Damp mopping involves substantial physical labor and is often performed inefficiently, particularly in taking the effort to keep the water and detergent changed often enough to avoid merely smearing the dirt around into a uniform film. Commercial floor scrubbers which are pushed or driven by the operator are often used instead of damp mopping on larger areas.

Approximately 30 billion square feet of floor are cleaned every day in the world, much on a contract basis at prices from $0.65 to $1.00 or more per square foot per year. It is estimated that contract cleaning in the U. S. is in excess of $10 billion per year and growing rapidly. The business is essentially recession proof and grows every year as new construction adds to the area to be cleaned.

The dominant costs of contract cleaning are direct labor, running to 80% of all costs. Personnel problems are tremendous, with heavy turnover and reliability and liability problems. Much of the labor is provided by transients, by temporary workers between jobs, and by new immigrants who move on to better jobs as soon as they can speak the language. Supervisors are in short supply and difficult to retain if competent.

The technical problems in robotic floor cleaning are primarily in navigation and in coping with "real world" issues (as compared with academic simulations). One needs to cover large areas with no missed spots, to detect and avoid obstacles, and to allow programming with little or no skills on the part of the operator. Real world problems include lack of maintenance for cleaning equipment, spills, bubble gum, pellets, boxes and other materials left in aisles, merchandise fallen or knocked from shelves or racks onto the floor, and sabotage.

Three rather different approaches to cleaning robot control have emerged in Japan, the US, and Europe. None can be said to provide a completely satisfactory solution as of the present date, but commercial prototypes are expected in the 1989-1990 time-frame that will substantially change the industry in the 1990's.

Cleaning Robots in Japan:

Two products have been introduced in Japan, Toshiba's "Autosweepy" and the Automax robot. The Toshiba design features a steering mechanism that allows the robot to translate sideways without changing its orientation. Markers are set up to define a small rectangular space and the robot executes a back and forth (or raster) pattern to fill the space, moving sideways one path width after each pass and reversing directions upon encountering a barrier. Only small spaces can be handled since the control system depends on dead reckoning to maintain its orientation and will drift over time and leave uncleaned areas on the floor. Obstacles such as pillars in the space are detected with ultrasonic sensors and avoided by moving sideways and then forward and then back to the original path. At present this robot is not considered a serious product opportunity since it requires an attendant to move temporary markers around to define the areas to be cleaned.

The Automax robot is much more impressive. Automax is a small company that has been working on mobile robots since 1975. The Automax cleaning robot was introduced in 1987. This new robot uses a gyroscope and encoders for dead reckoning and ultrasonics for local obstacle detection. The ultrasonic sensors and the bumper are used to let the machine automatically "learn" the boundary of a space, and an operator can use a joystick to intervene in teaching a boundary. Once the boundary is defined, a raster fill pattern is executed, with obstacle detection and avoidance. This system is very nicely packaged and works well in small, structured environments. Since all gyroscopes suffer from drift, the system cannot be used in very large spaces or spaces with many obstacles, since it will slowly drift out of orientation and miss areas of the floor. Electrolux-Euroclean AB of Sweden may sell the Automax robot in Europe as the AXV-01 (P. O. Box 127, S-66200 Amal, Sweden).

Cleaning Robots in Europe:

Several development projects are underway in Europe, particularly in France and Sweden. Electrolux AB of Sweden (ELUX) is the largest appliance manufacturer in the world (Eureka, Facit, Kent, and White Consolidated are trade names of Electrolux AB in the US; the US Electrolux was originally part of the Swedish Electrolux but is now completely independent). ELUX has sponsored the Automax work, work at Transitions Research Corporation (TRC) in the US, and has its own in-house developments.

The French are involved in several mobile robot projects. A multi-purpose modular mobile robot, "Robuter", and a vacuum cleaner robot, "AutoVacC", is being marketed in the U.S. by GSF SAFEWAY of Indianapolis, USA. and ROBOSOFT

SARL of Asnieres, France. A brochure containing the product specification is included in Appendix C/1. Further information on these products may be obtained from reference 7.

The Rail Association de Transport Parisienne, RATP, the French Metro (subways), contracted for cleaning robots two years ago for the Metro stations in Paris, France. A consortium of the French atomic energy commission, the University of Toulouse, and a company Midi-Robo received the contract. Several machines to clean platforms, to clean ceilings, and to clean subway cars are planned. Demonstrations of a cleaning machine are planned in 1988. The short term plan is to have an attendant with the machine at all times to meet union demands.

Cleaning Robots in the United States:

Several companies are interested in floor cleaning in the US. Many small firms that make or distribute cleaning chemicals and supplies (detergents and waxes and brushes and pads) are studying opportunities to provide complete cleaning services based on automatic cleaning. Cleaning machine companies are actively looking for navigation technology to automate their equipment.

Transitions Research Corporation has been under contract with AB Electrolux of Sweden to develop a prototype floor cleaning machine. A commercial floor scrubber has been modified and has successfully cleaned part of a school and part of an industrial building using teach and playback techniques and using sonar and vision for navigation. This system will be packaged and used in field test in 1989 and 1990.

University development projects include the University of Cincinnati, who is working with the Tenant company, a manufacturer of cleaning equipment. Mobile robot and automatic guided vehicle technology developed in projects at the Massachusetts Institute of Technology (MIT) and the Lehigh University have been proposed for cleaning applications. However, no products have been introduced to-date in the United States. The growing activity and interest in this area is expected to produce viable products by 1990.

5.2 MAIL DELIVERY ROBOTS

Mail delivery in office buildings is a structured and straightforward task that is labor intensive. Several products have addressed this market over the past decade.

The Bell and Howell Sprint Mail Delivery System is available as a commercial product and has in fact been on GSA schedule for Government application. The robot vehicle has 24 compartments for mail and follows a fixed delivery path, stopping at programmed points and beeping to announce a mail delivery. The robot waits until the start button is hit or until a fixed time has passed and then resumes its journey to the next delivery point. The fixed path is set with an invisible fluorescent dye which is sprayed onto the floor surface. For a carpeted floor, the fluorescent dye is sprayed onto the carpet; and for a waxed tile floor, first the old wax is stripped off, the dye is sprayed onto the unwaxed tiles, and the floor is rewaxed. A brochure is included in Appendix C/2. Further information on the product may be obtained from reference 8.

5.3 SECURITY ROBOTS

Denning Mobile Robotics Inc. of Wilmington, Massachusetts, is one of the leaders in promoting the use of robots in security applications. Denning was founded in February, 1982. The first products were modular research vehicles (mobile platforms) sold in 1984 and the first security unit, the Sentry, was sold in 1987. Excerpts from the marketing brochure are provided in Appendix C/3. Further information on the product may be obtained from reference 9.

The Sentry is 54 inches tall and weighs 485 pounds. It has microwave, infrared, and ultrasonic sensors to detect intruders and a smoke detector to detect fires. The robot also has a TV camera and a video recorder and can transmit the video image back to a guard at the communications station from which the robot is controlled. The robot navigates using dead reckoning and active beacons (infrared lights located on walls which provide directional information) and uses ultrasonic sensors to detect and avoid obstacles in its path. The primary function of the Sentry is that of a roving security guard conducting watch-clock tours. The mission is to detect an intruder or a fire and to summon help.

The Sentry is taught with teach mode programming the desired paths between beacons. Programs can then be executed in fixed or random patterns. The sentry can navigate in hallways and open areas and can pass through doorways. The ultrasonic range detectors sense obstacles and appropriate software directs the robot to avoid anything in its path. The ultrasonic detectors are located near the bottom of the robot and in a ring about its midsection at approximately table height. Obstacles at other heights might cause problems. A bumper stops the robot if it runs into anything. Facility modifications are required to add navigational beacons on walls along the robot's path.

Security Robot Development Projects:

Several security robot development projects have been undertaken by the Federal Government. An outdoor security vehicle was developed and demonstrated at the Naval Ocean Systems Center at San Diego, California. Another outdoor security vehicle was developed as a product by Robot Defense Systems, Inc., a Colorado company that has since gone out of business. This vehicle used a scanning laser ranging sensor for navigation. The Defense

Nuclear Agency has completed two phases of a four phase project to develop and demonstrate an outdoor security robot for military bases.

An indoor security robot along the lines of the Denning Sentry and with additional sensory capability has been developed by the Navy and has been tested at the Naval Surface Weapons Center at White Oak, Maryland. Sandia National Laboratories has developed an autonomous indoor mobile sentry robot for the Department of Energy (DOE). Oak Ridge National Laboratory has also been developing a general purpose autonomous robot for DOE for indoor use, one application of which would be security. It is expected that many of these research activities will also produce products to compete with the Denning's robots in both indoor and outdoor environments within the next several years.

5.4 STORAGE FACILITY OPERATIONS

Storage facilities operations, particularly bulk storage facility requiring handling of large heavy cartons/boxes, is a potential candidate for automation. Routine operations performed with a forklift (such as loading, unloading, storage and retrieval, etc). can be handled by robotics. Such an Automated Storage and Retrieval System is already employed by GSA at the U.S. Army Publication Center in Overland, Missouri. Further information on this automated facility may be obtained from reference 10.

5.5 WINDOW CLEANING ROBOTS

International Robotic Technologies of Marina Del Ray, California, has announced the Skywasher, a walking robot for cleaning windows and building exterior surfaces. The robot moves on vertical surfaces using suction cups to adhere to the surface. A fluid and wiper system enable the robot to wash windows as it travels down the building face. This robot is a derivative of another walking robot design, the "Marine Robot" which was designed to walk on the hulls of ships using brushes to clean the hulls. This design was announced in 1984. It appears that this robot is a prototype design and not yet a marketable product.

A product called "VACS" (Vacuum Adhering Crawler System) is marketed in the U. S. by the Pace Products Inc. of La Herbra, California. The "VACS" is manufactured by the O.N.O. Co. Ltd. of Tokyo, Japan. This robot is intended for painting, maintenance, and cleaning of buildings, tanks, and ships. Further information on the product may be obtained from reference 11.

Window cleaning is less attractive than floor cleaning for automation, because windows are not cleaned every day. Still, during the 1990's it can be expected that robot window washing will become common practice.

5.6 LAWN MOWING ROBOTS

Lawn mowing was mentioned earlier as a potential application for robotics. Several projects in Japan and in universities have been reviewed. No real product technology is expected in the near term future, although reports of working systems in Japan have been received.

Two basic problems appear in lawn mowing. One is navigation, the other is product liability. Outdoor navigation is very difficult, much more so than indoor navigation, because of the lack of structure, the three dimensional nature of the terrain, and the constantly changing lighting conditions. Mowing a lawn from one week to the next may be a very different task.

Technical Solutions Inc. of Sterling Virginia, has recently announced a prototype robotic lawn mowing called the "Lawn Ranger" [12,13]. The Lawn Ranger is battery powered and it is navigated by sensing the edge of uncut grass. To start a lawn moving task, the Lawn Ranger is manually guided once around the perimeter of the yard and any obstacles within the area, the machine is then shifted to automatic operation. The sensor system follows the border of uncut grass and guide the machine; and when no more high grass is detected, the machine shuts itself off. The lawn ranger is not yet a marketable product.

5.7 OTHER SERVICE ROBOTS

Some other interesting service robotic devices which were on display at the robotics trade show held in Detroit, Michigan, in June 1988, included the following (see Appendix C/4): Cybermation's " **Mobile Platform K2A**". This mobile robot can carry up to 350 pounds of payload and it can climb a 25 degree ramp and a 4 inch curb [14]. Transitions Research Corporation (TRC)'s "**LABMATE**", an autonomous mobile robot base which can carry up to 2000 lbs of payload; and "**HELPMATE**", a mobile robotic nurse that can carry out various tasks [15].

6. POTENTIAL APPLICATIONS.

The most promising near term applications of robotics for building operations and maintenance appear to be floor cleaning, mail delivery, and security. The Robosoft's "Auto VacC", Bell and Howell's "Mailmobile", and Denning's "Sentry Robot" are presented as examples of each of these areas. Other competitive products can be expected in the next several years. Relevant data on some current robotic products are presented in Table 5.

Table 5: Specifications of some Current Robot Products

Product	Auto VacC	Mailmobile	Sentry Robot
Manufacturer	Robosoft	Bell & Howell	Denning
Function	Floor Vacuuming	Mail Delivery	Security Patrol
Size(inches)	26 x 46 x 51	24 X 58 x 51	29 dia. X 54
Weight	440 lbs	650 lbs (vehicle) 800 lbs (capacity)	465 lbs
Mobility by	4 wheels	3 wheels	3 wheels
Top Speed	2.3 mph	1.2 mph	3 mph
Energy source	48 V batteries	24 V batteries	36 V batteries
Operation Time	8 hours	8 hours	14 hours
Navigation	Optical Encoders	Fluorescent Dye Stripe	Ultrasonic sensors
Teach Mode	Teach boundary or auto area coverage	Paint Stripe	Lead Through Program Routes
Obstacles	Avoids Ultrasonic range finder	Stops Proximity, sensors	Avoids Ultrasonic sensors
Price	$30,000	$25,000	$65,000

The economics of the mailmobile and cleaning robot are in terms of direct labor reduction. In-house labor for janitorial services, mail delivery, and other maintenance functions is in the range of $5.00 - $10.00 per hour in most companies. It appears that robotic floor cleaning and mailmobile will provide approximately two year payback.

The Denning Sentry is sold more on the basis of improved quality of service. The security robot provides incessant attention and replaces people from a hazardous and tedious task. At the current price, direct labor payback, depending on wage scale, is about three years.

Substantial cost reduction can be anticipated in the next several years as the technology matures. Any or all of these robotic applications can reduce the cost of operation and maintenance tasks in the GSA managed facilities.

7. POTENTIAL BARRIERS

Potential barrier to the use of robotic technologies (automation) for building operation and maintenance may be placed in three groupings: regulatory issues, personnel issues, and physical barriers,. These are discussed below. The focus will be on the physical barriers since these relate to the design and construction of buildings.

7.1 REGULATORY ISSUES

Regulatory issues are potentially a problem, particularly in elevator control. Existing codes or guidelines (such as exist in Connecticut State, and New York City) on elevator safety referring to automatic guided vehicles may be a barrier to introduction of new robotic systems in not allowing robots to use elevators used by people. However, our discussions [16] with the National Conference of States on Building Codes and Standards (NCSBCS), indicated that currently there are not any national codes or guidelines specifically dealing with the mobile robots. The service robotic technology is relatively new, and there is as yet an insufficient technical basis for recommending guidelines.

7.2 PERSONNEL ISSUES

Cooperation of the building occupants, including management, custodial, and security staff, is necessary for the successful use of robotics in building operation and maintenance. If building occupants want a new robotic system to fail, they will be able to make it fail. It takes a positive commitment to introduce any new technology successfully. This in turn requires motivational, educational and training programs for building occupants. The key emotional issue is almost always job security; people don't like menial or boring work, but they don't want to lose their income. A management commitment to job security and to retraining is necessary to overcome this barrier in any application of automation.

7.3 PHYSICAL BARRIERS

Several potential physical barriers to using automation in building operations were listed or implied in the discussion above. Greater definition will emerge from experience in testing and using new automation systems, but certain physical barriers are clear. Some potential barriers to the mobility and navigation of robots are listed below.

1. Halls and open spaces with no clear visual landmarks or no clean wall surfaces for navigation.

2. Doors with small width (less than 30 inches); recessed doors; and doors having opening mechanisms that cannot be operated by robots.

3. Obstructions such as area rugs, door mats, door stoppers, furniture and trash items left in the hallways.

4. Poorly located drinking water fountains, wall mounted ash trays, fire extinguishers, electrical outlets, etc.

5. Uncoordinated colors of wall and baseboard paints.

6. Sharp corners, pillars, alcoves, and recessed doors.

7. Utility closet dimensions too small for robots.

8. Lack of drains for emptying floor scrubbing robots.

9. Inter-floor mobility with special provisions for use of elevators may be required if a robot has to serve more than one floor.

8. GUIDELINES FOR THE USE OF ROBOTICS IN GSA BUILDINGS

To overcome physical barriers to the use of robotics for building operations and maintenance, modifications in both the robotic devices and the buildings are needed. The service robot technology, particularly robotic navigation, is relatively new and advancing rapidly; and most manufacturers, to remain competitive, keep upgrading their products. It is therefore envisioned that many of the above mentioned barriers may no longer be impediments to the newer robotic products. Nonetheless, guidelines for building design and construction are needed to accommodate the emerging robotic technologies.

The guidelines must be based on adequate technical knowledge of these robotic products. Research programs, including laboratory and field testing, are needed to obtain useful knowledge and better understating of the new robotic technologies. Once adequate test data and understanding of functional processes and navigation systems are available, the implications for building design and operation could be explored. Physical limitation to using robotics in buildings could be introduced in the design programming process for proper consideration. Procedures and practices could then be established and included as amendments/revisions within the GSA " Facility Standards for the Public Buildings Service PBS P 3430.1A " to insure accommodation of emerging new robotic technologies in federal buildings in the future.

These guidelines should cover such issues as elevator control interfaces, local area communication networks, robot communications interfaces, floor loading, lighting, door widths, and fire doors. In addition protruding items such as water fountains, fire extinguishers, pillars and other structural elements, walls and baseboards, floor tiles, carpets, and layout of maintenance support facilities and utility closets should be included. Other items will emerge as our experience grows.

While all of these issues cannot be determined at the present, some concepts are immediately clear. If a job/task is simple for a person and does not require moving furniture, then it will be possible for a robot to perform. The environment should be kept as structured and open and regular as possible if a robot is expected to navigate. Baseboards that provide a smooth transition to the floor can be cleaned; gaps and right angles cannot be cleaned well. Water fountains or coolers built into the wall allow floor cleaning; coolers in the hall or in alcoves make cleaning difficult (for a person as well as a machine). Area rugs and casual furniture are very difficult to cope with by a machine.

Suggestions for specific amendments to the GSA " Facility Standards for the Public Buildings Service PBS P 3430.1A " to accommodate the use of service robots in GSA buildings are presented in Appendix A. It is important to point out, that the amendments suggested in Appendix A are based on existing robotic products and some development projects, and on limited field experience and test data. Hence, these are not exhaustive, and as our knowledge base expands these should be refined and augmented.

9. RECOMMENDATIONS FOR GSA

The above review indicates a rapidly developing set of technologies that will provide increasing relevance to GSA requirements in future years. Since a number of applications and a range of changing technologies is involved, there is no single fixed set of recommendations that can be given to GSA to guide procurement and operating procedures for all time. Instead, an evolutionary evaluation and procedure development approach is needed.

Narrative descriptions, advertising material, and even video tapes do not provide any real understanding of the capabilities and limitations of new technologies. Actual hands-on demonstrations and tests of new equipment are essential to determine effectiveness and to gain real understanding of new approaches. It is, therefore, recommended that GSA develop both procedures and research programs for laboratory testing and evaluation of field installations of new robotic technologies. Such programs would insure accommodation of emerging new robotic technologies in Federal Buildings in the future.

Once adequate test data and understanding of process technologies (e.g. floor cleaning) and navigation technologies are obtained or available, the implications for building design and operation could be further explored. And as our knowledge base expands, the recommendations for revisions to the GSA design criteria could be refined and augmented.

When robots are actually introduced into the GSA facilities, educational and training programs will be needed to communicate with both the occupants of the buildings that might encounter the robots on either a casual or regular basis and the operating staff that will be responsible for operating and maintaining the robots. Such educational programs are a necessary part to introducing any new technology.

Some staff members knowledgeable in the introduction and use of new automation systems would be of great help to building managers as the technology diffuses. Such a group could grow out of any initial testing and evaluation effort and could also be responsible for developing training programs for field managers. These staff members could keep abreast with the latest developments in service robotics by communicating with such professional organizations as the Robotic Industries Association (RIA), 900 Victors Way, P.O. Box 3724, Ann Arbor, MI.48106, and the Society of Manufacturing Engineering (SME), One SME drive, P.O. Box 930, Dearborn, MI. 48121.

10. ACKNOWLEDGEMENT

This work is sponsored by the Public Building Service, General Services Administration, Washington,D.C. 20405.

11. REFERENCES

1. Eakin, D., General Services Administration, Public Buildings service, Washington, DC 20405,"Personal communications".

2. GSA Public Building Service Fund and Program Status Report of Real Property Management and Staff, June, 1987, Region Nationwide.

3. Eisenstein, P. A., "Service Robots Giving New Freedom to Handicapped," The Christian Science Monitor, July 7, 1988; page 11.

4. Stauffer, R. N.,"Robots Reach Out to Touch Nonindustrial Applications," Robotics Today, October,1987, 19-22.

5. Bylinsky, G.,"Invasion of the Service Robots," Fortune (technology), September 14, 1987.

6. Smith, B. M., Albus, J. S., and Barbara, A. J.," A Glossary of terms for Robotics," SME paper MS 83-914, Dearborn, MI: Society of manufacturer engineers, 1983.

7. Ryerson, C., GSF Safeway 2911 West Washington Street, Indianapolis, IN. 46222, "Personal communications".

8. Volie, D. A., Bell & Howell Mailmobile Operations, 411 E. Roosevelt Street, Zeeland, Michigan 49464-1395, "Personal communications".

9. Isbell, Chris, Denning Mobile Robotic Incorporated, 21 Concord Street, Wilmington, Massachusetts 01887, "Personal communications" .

10. Casey, J. P., Design and Construction Division, Public Building Service, General Services Administration, Region 6, Kansas City, Missouri, "personal communications".

11. Nakao, Y.,Pace Products INC., Beach Plaza, 1251-c SO. Beach Blvd., La Habra, CALIF. 90631, "Personal communications" .

12. Dillingham, S.," Robotic Lawn Mower Trims Elbow Grease," Insights, Sep.19,1988, (p.45), 3600 New York Ave. N.E. Washington, DC 20002.

13. Hammond, J., Technical Solutions Inc. 8110 Frostfield Court, Frederick, MD. 21701, " Personal communications".

14. Holland, J. H., Cybermation INC., 5457 JAE Valley Rd., Roanoke, Virginia 24014, "Personal communications".

15. Engleberger, G., Transitions Research Corporation, 15 Great Pasture Rd. Danbury, Connecticut 06810, "Personal communications" .

16. Connover, D., and Arbib, J.,National Conference of States on Building Codes and Standards (NCSBCS), 481 Carlisle Drive, Herndon, Virginia, "Personal communications".

APPENDIX A

SUGGESTED AMENDMENTS THE GSA FACILITY STANDARDS FOR THE PUBLIC BUILDING SERVICE PBS P 3430.1A

Suggested amendments to the GSA "Facility Standards for the Public Buildings Service PBS P 3430.1A " for accommodating robotic products for building maintenance, operations, and delivery of some specific services are presented below. It seems appropriate to place the suggested amendments in Chapter 8 of the GSA Handbook by adding a new "PART 11. DESIGN FOR USE OF SERVICE ROBOTS "

These suggested amendments should be introduced in the design programming of specific building projects for proper considerations.

It is important to point out, that the suggested amendments are based on existing robotic products and some development projects, and on limited field experience and test data. Therefore, these are not exhaustive, and as our knowledge base expand these should be refined and augmented.

The service robot technology is still growing and advancing, therefore, it is likely that many of the barriers mentioned in this report, may not be impediments to the newer robotic products.

CHAPTER 1. BASIC REQUIREMENTS

PART 2. DESIGN PRINCIPLES

22. Environment and functional needs.

f. Maintenance and operation. Design of buildings should satisfy the functional requirements for the use of robotics for certain operation and maintenance tasks such as floor cleaning, mail delivery, and security. The specific requirements applicable to the use of robots are addressed in chapter 8.

CHAPTER 8. SPECIAL DESIGN ISSUES

PART 11. DESIGN FOR USE OF SERVICE ROBOTS

117. General. Design of various building elements, such as corridors, hallways, office partition walls, floors and floor coverings, public use items doorways, lights and electric outlets, closets spaces, etc. should meet all the relevant requirements specified in below.

118. Floors.

a. Cleaning consideration: Finished floors and floor coverings should allow for the use of floor scrubbing and vacuum cleaning robots. Carpeting, if used, should be uniform wall to wall carpeting; the use of shag rugs and area rugs should be avoided.

b. Loading for Raised Flooring Systems: Raised flooring systems (panels, framing, stringers, understructure, etc.) should be designed to support the additional loads that are likely to be exerted by moving robots. Particular consideration should be given to the rolling load, since it has more damaging effect on the floor panels than a static load. Rolling loads are dependent on the number, size, and hardness of the wheel, and on the weight of the robot.

119. **Walls and Partitions.**

a. Minimum separation: In order to enhance the use of robotics, minimum spacing between walls and other objects should be 30 inches. The use of alcoves and protruding elements should be avoided.

This spacing specification is based on the dimensional data of currently available products, see Table 5; and it may require revision for products with larger dimensions. Unless the alcoves are very large, floor areas would be difficult to clean by robots.

b. Painting colors. In order to accommodate robotic product, walls near the baseboard should be of uniform colors, and baseboards should be of a contrasting color to the floor and to the walls.

The contrasting colors by providing detectable visual landmarks would enhance the navigation of robots, particularly for robots using vision systems for navigation.

120. **Doors.**

a. Dimensions: To allow for use of robotics, the minimum width of doors should be 30 inches.

The minimum door dimension specified is based on available data on product (Table 5), and it may require revision.

b. Hardware: The door's hardware should allow for robotic operation.

For example, use of bidirectional push or automatic opening mechanisms should be adapted for service area and hallway doors.

However, for safety consideration, use of these door opening mechanisms would not be permissible for stairwell doors, and for doors to pressurized rooms and other restricted areas.

121. Lights: Locations, style and color of light fixture should be carefully coordinated to enhance mobility and navigation of robots. For example, lighting in the corridors and hallways should be of rectilinear patterns aligned with rooms or halls to enhance the robotics navigation.

The specified lighting scheme, by providing uniform illumination, enhances the navigation of robotic devices using polaroid sensors and vision systems for navigation.

122. **Support Spaces**:

a. **Snack bars and vending facilities**: Location & placement of snack bars and vending facilities should be properly designed to permit the use of service robots. Particularly, if floor cleaning robots are to be used, separation between walls and vending machines and between two machines is important and require proper consideration.

b. **Public telephones**: Public telephones should be situated to avoid interference with the mobility of robots.

c. **Public Use Items**: Public use items such as drinking water fountains, wall mounted ash trays, and fire extinguisher should be situated to avoid interference with the mobility of robots.

d. **Service area for robots**: Strategically located facilities for storing and servicing robotic devices should be provided. These facilities should include appropriate electrical outlets for charging the batteries of robots, and adequate water supply and drainage for changing water and detergent for floor scrubbing robots.

APPENDIX B : Robotic Navigation Technology

Sensors for navigation include ultrasonic ranging, infrared ranging, laser ranging, monocular and binocular vision, active and passive beacons, and various dead reckoning schemes including wheel encoders and gyroscopes.

The starting point is usually wheel encoders and Polaroid ultrasonic range sensors. Encoders provide wheel position essentially at no extra cost since they are used for servo control of the wheels. Slippage introduces errors as the robot navigates, so dead reckoning from wheel encoders is good only over short distances to a few meters. The Polaroid sensors were designed to provide focus for cameras and are inexpensive. While they provide impressive performance in laboratory tests, researchers have found that navigation using these sensors is difficult because of problems with specular reflections, standing waves, corner reflections, noise sensitivity, and beam spread.

Ultrasonic sensors also have the problem that the signals propagate at the speed of sound, about 1 foot per millisecond in air. Ranging to maximum distances of 35 feet takes 70 milliseconds for a sound wave to reach a target and return. Waiting some additional time for multiple path echoes to die out before starting another measurement increases the time for a single measurement to about 100 milliseconds. For a single transducer, this is a useful rate, but for an array of 10 to 100 transducers the rate is too slow for real time navigation. Firing can be overlapped and range terminated at a few feet, but standing waves and echoes then produce false signals that require more sophisticated data handling.

With care, the Polaroid sensors can provide useful data at low cost and are extremely useful in obstacle avoidance. European and Japanese projects have tended to use the higher frequency ceramic transducers that have a separate emitter and receiver with a range of a meter or so. This avoids many of the timing and crosstalk problems of the Polaroids and provides very useful obstacle avoidance data.

Beacons have also received widespread interest, and these are used in many "off-wire" automated guided vehicle experiments in materials transport in manufacturing and in the Denning security robot system described earlier. Beacons include active flashing infrared diodes or lights and various reflective tapes or reflectors with an active light source on the vehicle. Beacons can be used to get both bearing and range by measuring azimuth and elevation angles. Beacons must be placed at regular intervals to provide registration of the robot along its path. Dead reckoning using encoders or gyroscopes or both is used between beacons.

Vision and laser ranging systems provide images of the environment of the robot. At the present time, no commercial systems have been introduced with vision, but active research work in Government, universities, and industry is expected to produce cost effective solutions in the near future. Vision provides far more information than any of the simpler sensors described above, but interpretation of the data requires time consuming and expensive processing. Laser ranging can provide images in terms of depth at rates faster than one frame per second, but their use in mobile vehicles has been limited to advanced military research projects because of costs in the $100,000 range.

Once the robot has data on its environment, it can carry out a program to navigate in that environment. Initial products on the market feature one of two approaches to programming and navigation. The first approach is teach and playback, in which the robot is walked through a program and then plays it back. The second is area coverage, in which the perimeter of an area is taught and then the area is automatically covered with a collapsing pocket or raster pattern (for floor cleaning).

Experiments in navigation have included map or model-based navigation, map building or learning systems, and mapless or local algorithm systems. The first concept, map based navigation, requires that the model or map of the environment be entered into the control computer by the programmer. The robot then compares sensor data with this map to determine where it is. The problems here are entry of the data in a convenient way and interpretation of potentially abstract data in terms of real sensor signals. The advantage is interpretation and avoidance of obstacles.

Map building or learning systems represent the focus of much research at the moment. Conceptually, this is an intriguing concept. For example, one can imagine turning loose a cleaning robot in a new environment in the evening, and returning in the morning to have the building clean. This is the ultimate in user-friendly systems, but clearly the technical problems in interpreting sensor data from unknown sources is very difficult. We believe that this is some years in the future for commercial products except for very constrained environments. For example, a supermarket might be sufficiently constrained for map building, but a typical retail store of 100,000 square feet would not be.

Mapless navigation is another intriguing concept. The idea is that only local sensor data is used to influence the behavior of the robot. That data is used and then discarded, so the robot has no memory. Finite state automata theory can then be applied to the control of the robot, providing potentially very low cost control. In the near term, this approach is again only possible in simple constrained environments or as an adjunct of more traditional approaches. As an example, obstacle avoidance algorithms have been described which require only local sensing and no global knowledge. Once avoided, the obstacle is forgotten. Another example is a random path area cleaning program where the robot covers an area within a physical boundary. Good results can be obtained with simple geometric areas in a short time.

Progress is being made rapidly in understanding the problems of sensing and control of a mobile robot. Initial rather simple systems are reaching the market, and increasing sophistication will be seen over the next several years. During the 1990's, mobile robots will mature rapidly in addressing many service sector applications.

APPENDIX C

Brochures of Some Robotic Products

In this appendix brochures of some robotic products are reproduced.

C/1. French AutoVacC a Vacuum cleaning Robot

C/2. Bell and Howell Mail Delivery Robot

C/3. Denning Security Robots

C/4. Other Mobile Robots

GSF

Auto VacC™

the Autonomous industrial Vacuum Cleaner

Auto VacC™ is an Robotic Industrial Vacuum Cleaner which can be used by industrial cleaning professionals in 3 different ways:

- as a remotely operated device, for dangerous or white rooms cleaning;
- as a teaching-by-showing and repeat device for spacious offices and rooms;
- as an autonomous robot, for big halls (airports, shopping centers...).

During operation, an ultrasonic range finder allows unexpected obstacles detection and avoidance.

Several technical features, such as floor tool motions, electrically adjustable depression (from 900 to 2000 mH_2O) and electrical lift of vacuum cleaner motor block make **Auto VacC™**, the really first Robotic Industrial Vacuum Cleaner, easy to use by non technical workers.

GSF SAFEWAY 99/11 Washington St. INDIANAPOLIS IN 46222 USA
Tel. : (317) 635 57 32 - Fax : (317) 262 49 56

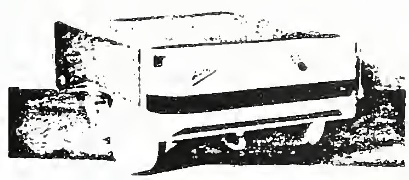
TECHNICAL SPECIFICATIONS*

Size	:	115 cm (46") length, 65 cm (26") width, 130 cm (51") height.
Weight	:	about 2000 Kg (440 Lbs), batteries included.
Speed	:	from 5 cm/s to 1 m/s (0 - 40 in/s).
Batteries	:	4 x 12 Volts 60 Ah sealed batteries (power supply 48 Volts).
Motors	:	2 x 300 Watts DC Motors, 48 Volts.
Steering	:	differential steering, by using relative velocities of the 2 propulsive wheels.
Positionning accuracy	:	by optical encoders < 1 mm odometric estimation of the position, in mm and 10^{-1} degrees.
Embedded calculator	:	VMEbus, 2 68000 8MHz microprocessors.
Operating system	:	ALBATROS™.
Programming	:	• **Interactive control** from a host machine, by sending a receiving ASCII messages through a wireless modem (remotely operated). • **Pendant** (teaching-by-showing). • **From a Macintosh** (autonomous mode).
Options	:	• Complete (both hardware and software) for ultrasonic sensors (until 96 sensors). • Vision system. • Broad choice of I/O (analog, logical...). • 9600 bauds wireless modem for remote control and programs loading. ...
Vacuum cleaner	:	• Industrial vacuum cleaner developed by **RIBO**, type A2T with mobile floor tool. • Capacity of the tank : 25 liters. • Depression (mm H_2O) : adjustable from 900 to 2000. • Air volume : 3900 liters/mm. • Wide choice of tools and extensions. • Electrical lift of motor block for easy tank emptying.

GSF SAFEWAY 99/11 Washington St. INDIANAPOLIS IN 46222 USA
Tel. : (317) 635 57 32 - Fax : (317) 262 49 56

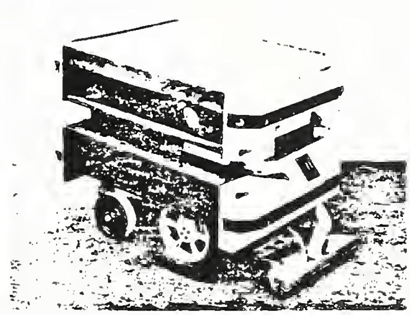
ROBUTER ™

The ROBUTER™ is a new concept in the field of mobile Robotics : it is the joining of a mobile ROBot and a powerful compUTER. The ROBUTER™ is the first mobile robot which ha been designed to be totally open, both at the hardware and software levels. With a standardized industrial bus (VMEbus), any commercially available board can be added. With ALBATROS™, several devices such as high level sensors, industrial robots, single axis ... can be easily integrated into the existing digital controller.



for research purposes...
(doc. **INRIA**)

for industrial applications...
(doc. **GSF**)



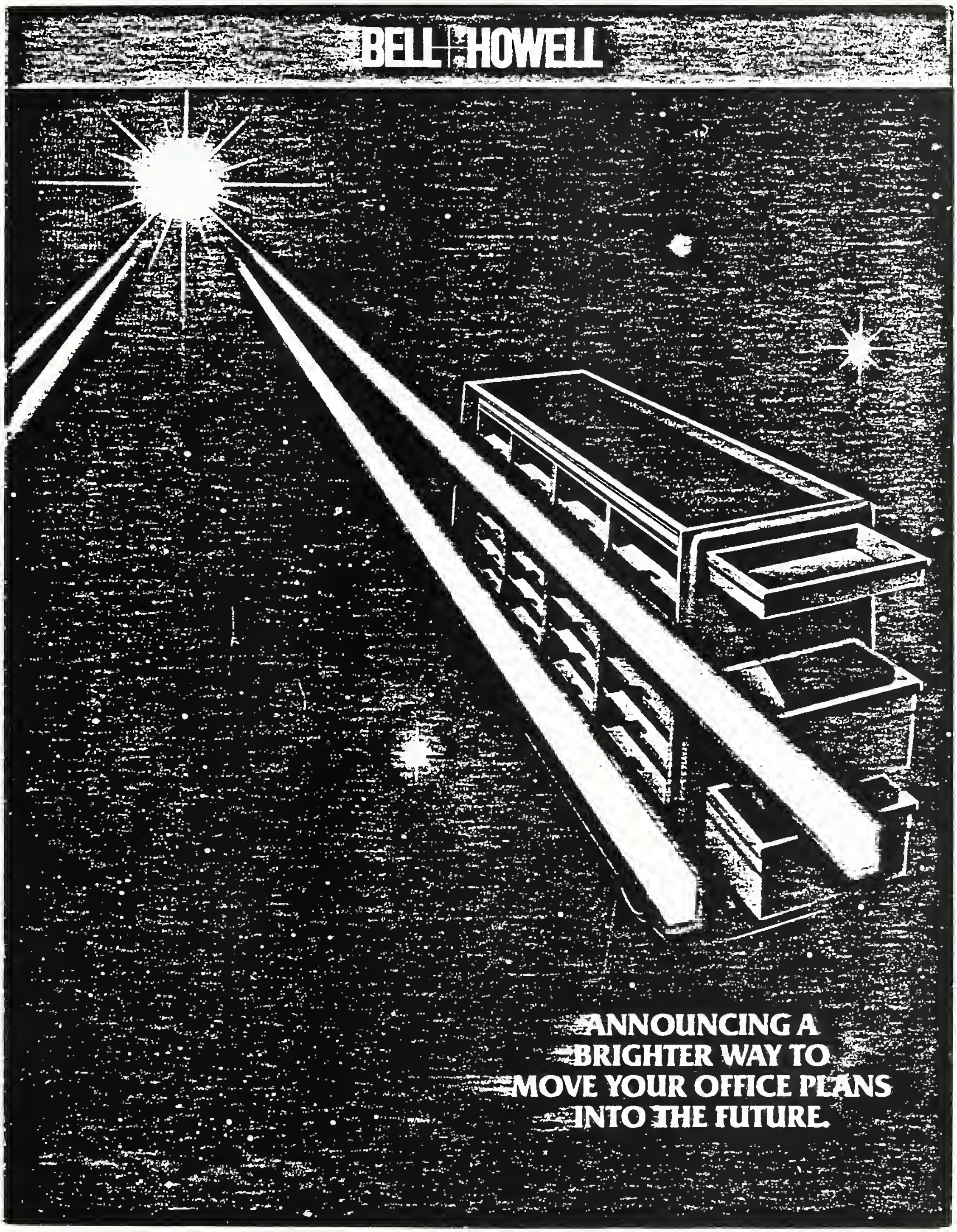
Robuter Design Inc. 29/11 Washington St. INDIANAPOLIS IN 46222 U.S.A.
Tel : (317) 635 57 32 Fax : (317) 262 49 56

TECHNICAL SPECIFICATIONS*

Size :	1 m (40") length, 68 cm (27") width,50 cm (20") height
Weight :	about 150 Kg (333 Lbs), batteries included
Load :	about 150 Kg (333 Lbs) available for the application
Speed :	from 5 cm/s to 1 m/s (0 - 40 in/s)
Batteries :	4 X 12 Volts 60 Ah sealed batteries (power supply 48 Volts)
Motors :	2x 300 Watts DC Motors, 48 Volts
Steering :	differential steering, by using relative velocities of the 2 propulsive wheels
Positionning accuracy :	by optical encoders < 1 mm odometric estimation of the position, in mm and 10^{-1} degree
Embedded calculator :	VME bus with 5 slots, 68000 8MHZ I/0 : available 2x32 bits counters for optical encoders 2x12 bits analog outputs 8 optoisolated outputs 8 optoisolated inputs power supply : 5 Volts 8 Amps, +/-12 Volts 1.7 Amps
Operating system :	ALBATROS™, a Real-Time Operating System specifically designed for multi-axes control. Its main feature is its modularity which simplifies the addition of other devices (a robot) or sensors (ultrasonic range finder ...)
Programming :	**Interactive control** from a host machine, by sending and receiving ASCII messages through a wireless modem. By **developing and downloading** application programs on a host machine.High-level language (C, Pascal ...) can be used (MACINTOSH or UNIX)
Options :	. ASDW (Albatros™ Development Software Workshop) . Complete (both hardware and software) for ultrasonic sensors (until 90 sensors) . Vision system . Broad choice of I/O (analog, logical ...) . 9600 bauds wireless modem for remote control and programs loading . Application tray, for research and development. . Remote control from graphic screen . Multi-processor computer

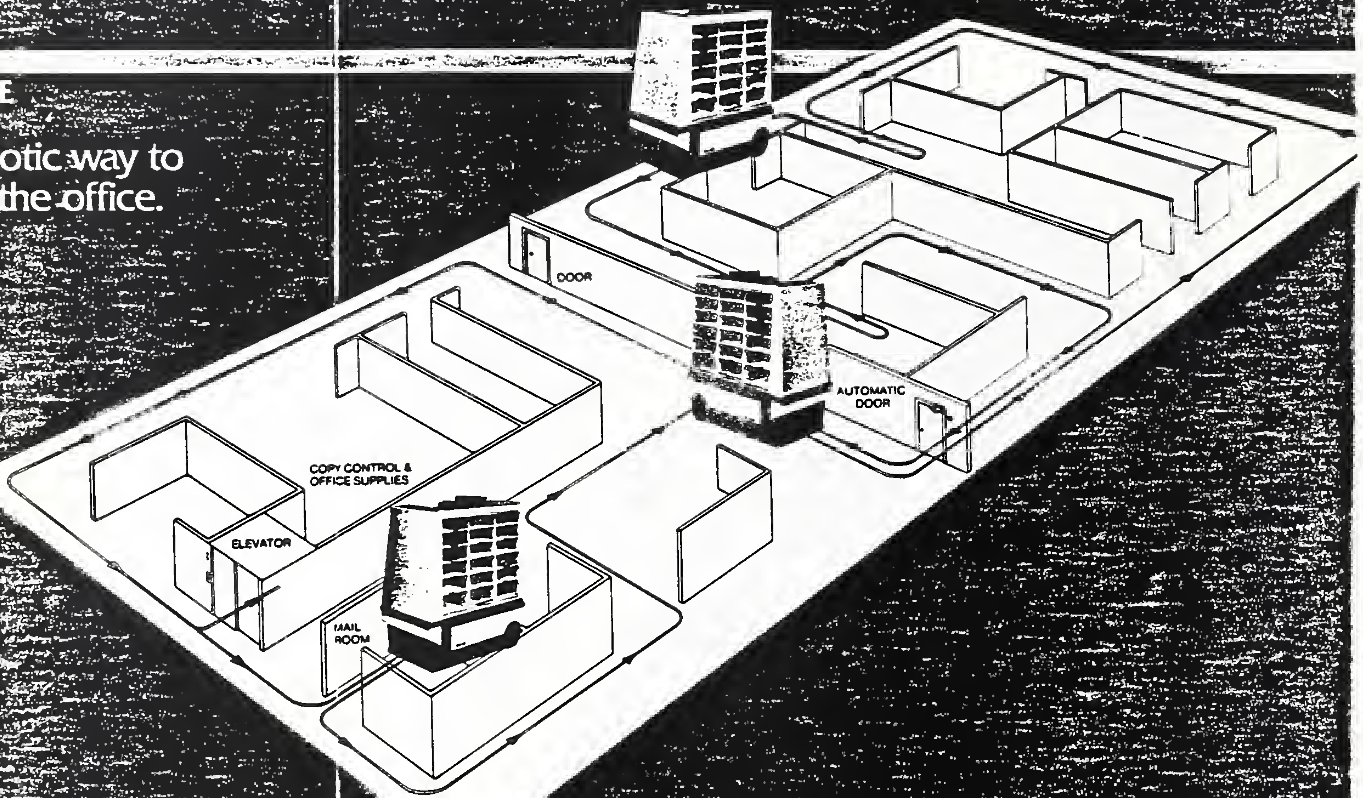
*these are preliminary specifications, subject to change

Robuter Design Inc. 29/11 Washington St. INDIANAPOLIS IN 46222 U.S.A.
Tel : (317) 635 57 32 Fax : (317) 262 49 56


BELL HOWELL
ANNOUNCING A
BRIGHTER WAY TO
MOVE YOUR OFFICE PLANS
INTO THE FUTURE.

LE

botic way to
the office.



…right for almost any site.
If you're planning an office with at least 10,000 square feet for 100 people or more, the Sprint Mail Delivery Vehicle makes good design sense for you. And since it does the work of two messengers or more, the vehicle makes good financial sense, too. Like clockwork, it makes its rounds over eight times a day, smoothing out employee work loads and increasing information flow. With this added efficiency, other automated equipment investments pay off faster. And time-sensitive materials such as invoices, remittances and correspondence—are delivered to the right desk sooner. Which dramatically enhances your clients' cash flow.

It works wonders for productivity.
With a Sprint Mail Delivery Vehicle doing the footwork, executive and non-executive personnel alike are freed to handle more meaningful tasks. Personnel can work in their areas of expertise without interruption, greatly increasing productivity while decreasing the vehicle's payback time. In offices across the country, managers have discovered that by linking up-to-the-minute information to the right people via the Sprint Mail Delivery Vehicle, everyone can improve their job performance. What's more, the vehicle eliminates costly employee absenteeism and turnover.

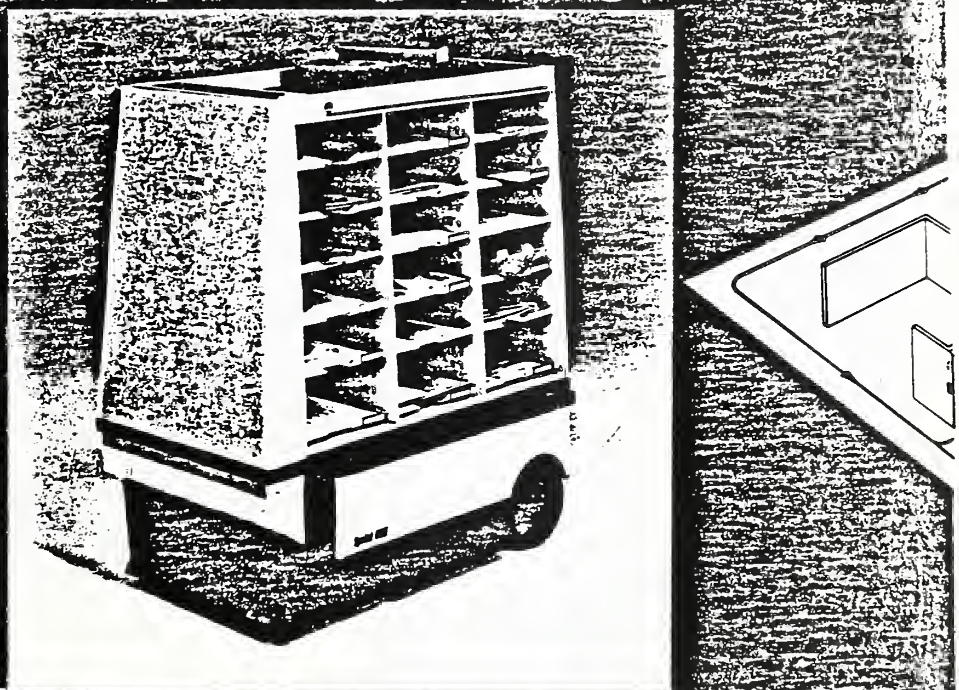
It's built for the future.
Bell & Howell Mail Delivery Vehicles are non-stop performers, too. They boast a collective track record of over a quarter million annual miles, with an uptime that averages over 98%. Contributing to that outstanding record is Bell & Howell's comprehensive pre-installation service to orient office personnel to the use of the vehicle. As well as one of the most complete, reliable Service Maintenance Programs in the industry, placing primary responsibility on the manufacturer. The Sprint Mail Delivery Vehicle is dependable automation that will see the offices you design through this century. Into the next.

MEET THE

Sprint™

MAIL DELIVERY VEHICLE

The compact, cost-effective, robotic way to speed information throughout the office.



You have bright plans for your future offices.

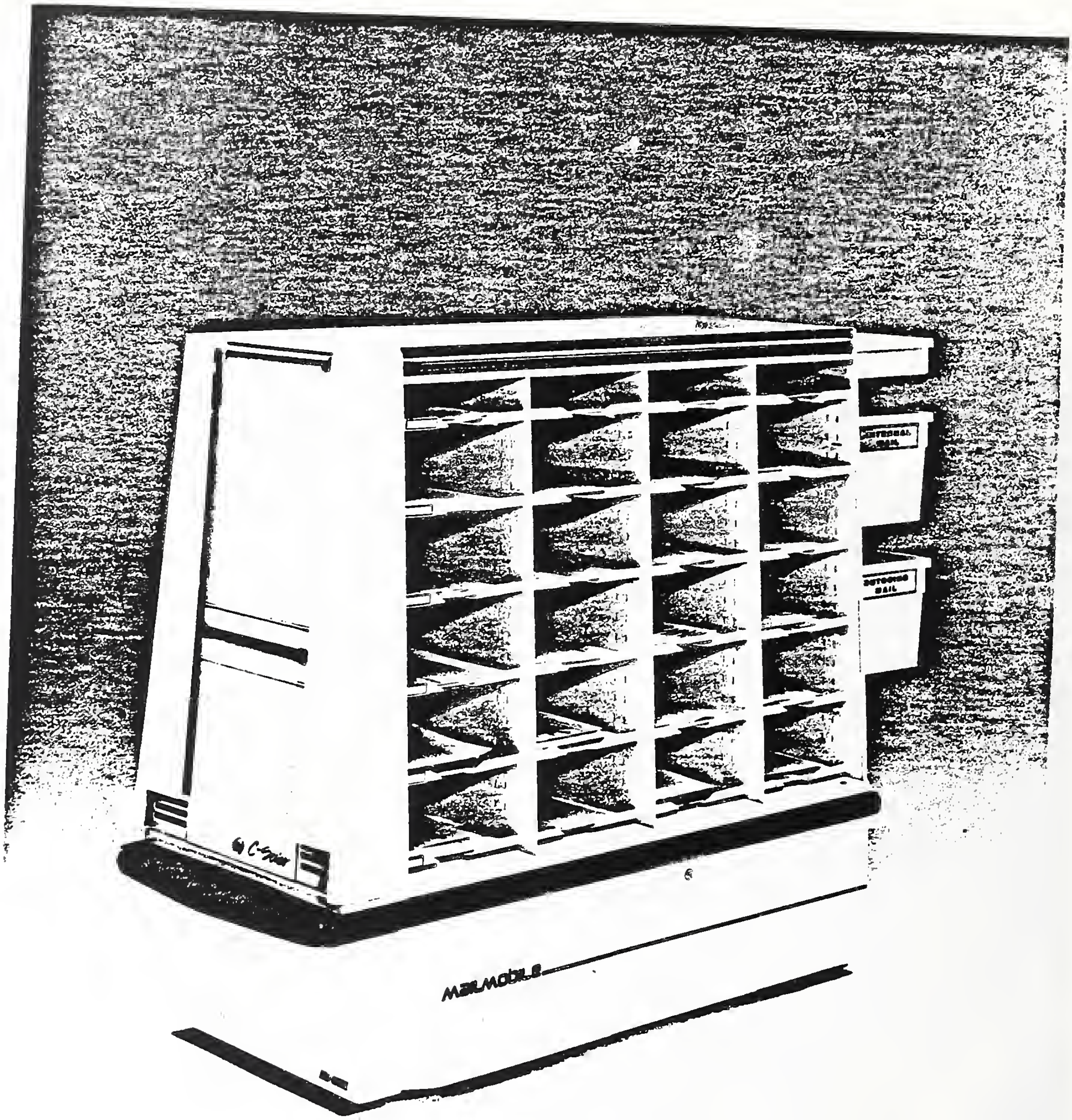
The office of tomorrow is the office you're designing today. You want it progressive. Fully automated. So into your plans you integrate computers, word processors, high speed copiers…the state-of-the-art equipment that will move information at peak efficiency. But that information-efficient office you're designing for tomorrow could be slowed down by yesterday's hand mail delivery.

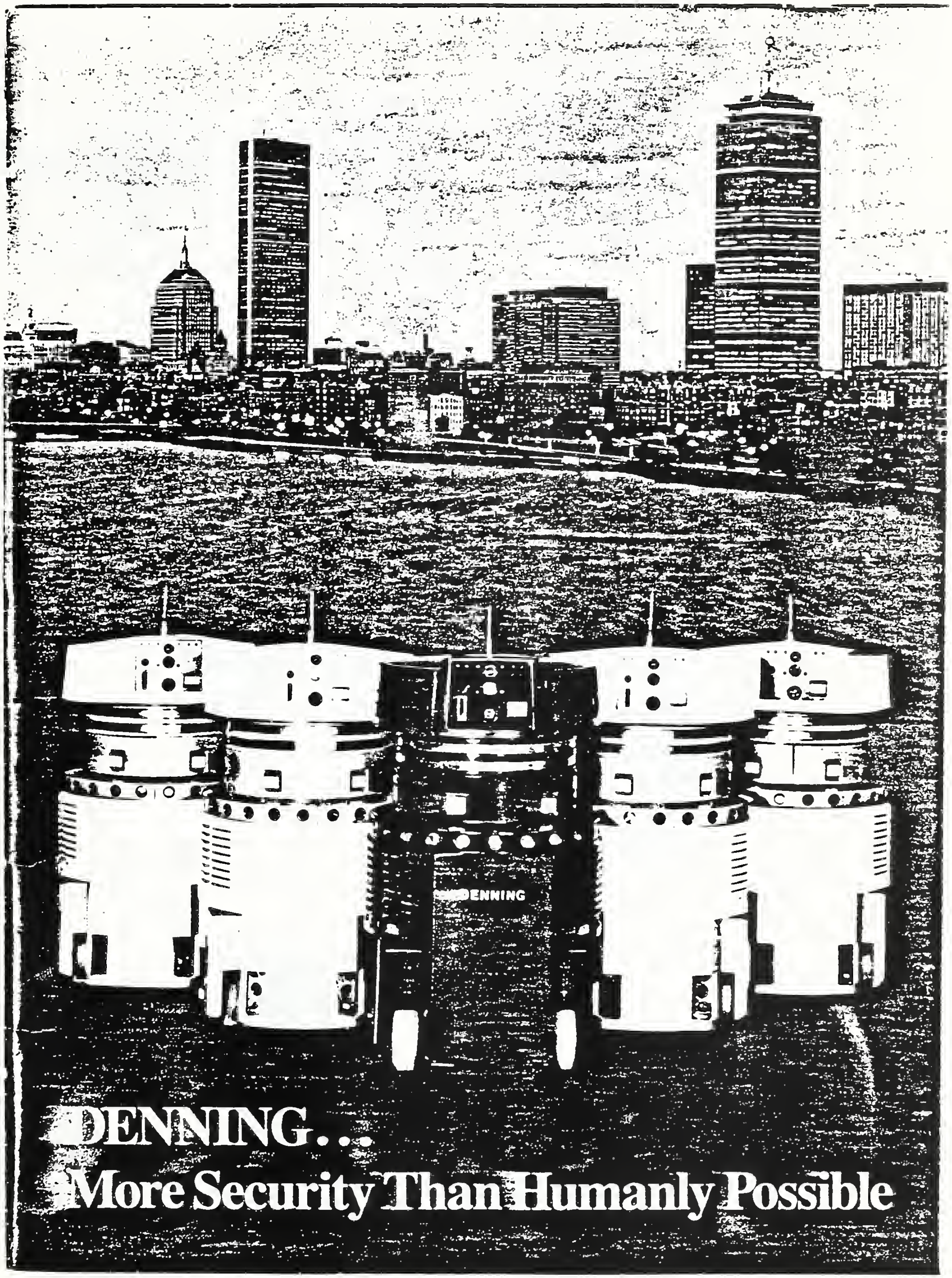
That's why we designed the Sprint Mail Delivery Vehicle.

The vehicle is a self-propelled, robotic delivery vehicle, specifically engineered to fit into tomorrow's compact, multilevel offices. It offers all the advantages of our famous Mailmobile® System, but in a smaller, smarter, more affordable package. Following a virtually invisible guidepath that can always be rerouted, the vehicle travels from office to office, carrying mail, computer media, office supplies—just about anything. Plus a variety of options permit it to perform special functions, such as maneuvering in close quarters or stopping at selectable stops. It even travels "back to base" for recharging!

It's right for almost any size.

you're planning an office with 10,000 square feet for 100 peop more, the Sprint Mail Delivery V makes good design sense for yo And since it does the work of tw sengers or more, the vehicle ma good financial sense, too. Like c work, it makes its rounds over e times a day, smoothing out emp work loads and increasing infor flow. With this added efficiency, automated equipment investme off faster. And time-sensitive ma —such as invoices, remittances a correspondence—are delivered right desk sooner. Which dramat enhances your clients' cash flow.


MAILMOBILE


DENNING
DENNING...
More Security Than Humanly Possible

More Security Than Humanly Possible

It's 9 p.m. Your facility is dark and the halls are empty. A Sentry quietly leaves its Recharge Station and begins its patrol cycle, alert for intruders and potential hazards. Robot status, constantly transmitted to your Communication Station, instantly alerts you of a security breach – an intruder on the premises. One glance at the Communication Station monitor provides you with the information you need to take command. You apprehend the intruder and your facility is again secure.

At 7 a.m., after a night of alert surveillance, the robot automatically returns to its Recharge Station for battery recharge in preparation for its next tour of duty.

The Denning Sentry Security System, a blend of computer science, mobile robotics, and security technology, is an entirely new, reliable way of protecting buildings. If you have concerns about whether your method of security is adequate, you will want to learn more about the Sentry.

The Sentry™ Robot

Standing four feet tall, and powered by three 80 amp hour gel-cell batteries, the Sentry travels at a rate of up to three miles per hour. The Sentry patrols fourteen continuous hours at full charge or at a four-to-one patrol/charge ratio, convenient for extended long-term surveillance. An ultrasonic sensor ring enables the robot to navigate through your facility, avoiding obstacles in its path.

The Sentry utilizes a variety of sophisticated sensors which relay information to its on-board computers for evaluation and immediate transmission to the Communication Station.

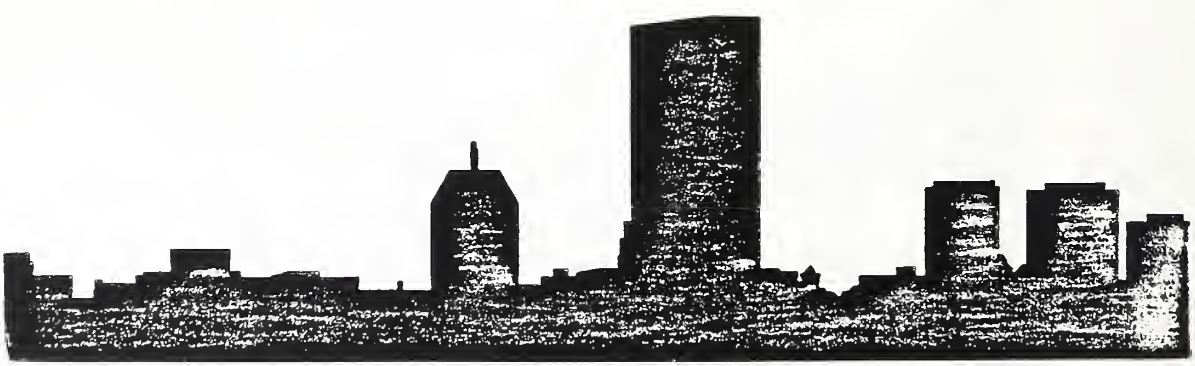
Microwave	—	motion detection of intruders
Infrared	—	heat sensing of intruders
Smoke detector	—	detects potential fire hazards
CCTV	—	video recording of patrol and immediate visual information for guard at Communication Station
Ultrasonics	—	object avoidance and path navigation during patrol

Options also available include gas detectors, humidity and temperature sensors, one-way and two-way audio communications, sirens, and spotlights.

The Sentry will run random or predetermined routes, increasing its surprise potential, or allowing you to place emphasis on your special high risk areas. If sensor data indicates an alarm situation, a warning will sound at the Communication Station, alerting your guard to take whatever action is required. If a guard is not present, the Communication Station will contact appropriate outside sources (police or fire department, or other of your choice) through a telephone modem.

The Sentry can be transported easily from one site to another to provide security for temporary inventories or in times of significant threat. It is ideal for those times when you are caught shorthanded, with too much to protect and too few men to do it.

This type of security is no longer found only in your imagination!



MRV-2

The MRV-2 is the next step up in the family and includes all of the MRV-1 features plus an 8 slot STD bus card cage with Denning's own 2 axis motor control card. Encoders on both motors provide feedback for full integral position and speed control. The chassis is digitally compensated to insure unconditional motion stability with any load up to the maximum. Speed, acceleration, and position may be specified for trapezoidal trajectory control.

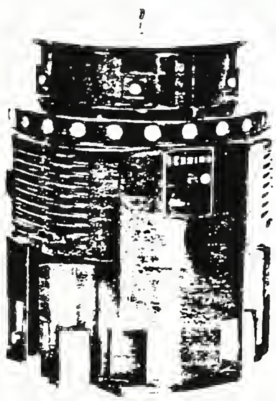
The MRV-2 may be controlled by a standard terminal via an umbilical cable, by a battery operated "lap computer" on board, or it can be used under the control of a host processor. The host processor may reside on board in the STD bus card cage, on the Payload plate in a customer supplied chassis of any bus type, or off-board via an RS-232 umbilical cable.

MRV-2 STANDARD FEATURES

- All MRV-1 features
- 100 line shaft encoders on steer and drive motors
- Hall effect index switch on steer axis
- 8 slot STD card cage
- Intelligent 2 axis motor controller with these features:
  - Hitachi 8 Mhz CMOS 64180 microprocessor
  - 64K static RAM, 32 K EPROM
  - 2 RS-232 serial ports up to 38.4 K baud
  - Operation as STD bus slave processor or stand alone
  - 2K x 8 STD bus dual port RAM, mode 2 vectored interrupt
  - Velocity mode joystick
  - Motor and amplifier temperature monitoring
  - Monitor, STD communication and exerciser software in EPROM

MRV-3

The MRV-3 is the fully intelligent vehicle with its on board 68000 system in addition to full servo control and all MRV-1 features. An additional 8 slot STD bus card cage is provided for the 68000 system. The OS-9 Real-Time operating system is used for high speed operation on the 68000 that contains 512 K Bytes of dynamic RAM, Kernel in EPROM, a 3½ inch floppy disc and Real-Time Clock. Control of the Motor servo subsystem is via a multidrop serial bus that runs at 38.4 K Baud and is fully expandable to additional intelligent subsystems available as options from Denning.



MRV-3 STANDARD FEATURES

- All MRV-1 and MRV-2 features
- Servo control subsystem with Hitachi 64180 processor
- 68000 on board Host system with 512 K Byte dynamic RAM
- 3½ inch floppy disc drive
- OS-9 operating system
- Real-Time Clock
- Multi drop Serial Bus for multiprocessor communication
- Additional +5 volt 5 amp DC-DC converter
- Additional +12 volt 2.5 amp DC-DC converter
- Second Multimate expansion connector to Payload Plate

SPECIFICATIONS

Size	20"H x 27" Dia.
Weight	260 Lbs.
Payload	300 Lbs.
Ground Clearance	2.5 Inches
Max Speed	5 Ft./Sec. (300 Lb. Load)
Climbing Ability	1 Inch Threshold (300 Lb. Load)
10% Ramp Speed	1 Ft./Sec. (300 Lb. Load)
Battery Power	36 VDC 40 Ahr. Rechargeable
Drive Amplifier	600 Watts Continuous 1200 Peak
Steer Amplifier	200 Watts Continuous 300 Peak
Servo Input (MRV-1)	± 10 Volts Drive & Steer
User DC Power:	
MRV-1°	5 VDC @ 4.5 Amps
	± 15 VDC @ 0.9 Amps
MRV-2°	5 VDC @ 4 Amps
	± 15 VDC @0.8 Amps
MRV-3	5 VDC @ 4 Amps
	5 VDC @ 1 Amp
	12 VDC @ 2 Amps
	± 15 VDC @ 0.8 Amps
°More power available with additional optional converter modules.	
Communication (MRV-2 & MRV-3)	STD bus parallel or RS232 at up to 38.4 K baud
RAM (MRV-3)	512 K Bytes
Floppy Disc (MRV-3)	360 K Bytes

MRV-3 OPTIONS

- Ultrasonic Ring Subsystem for object avoidance and navigation
- Radio remote data link
- Directional bumper switches
- Analog on board system status monitor
- Rotating head platform with slip ring interface

HEAD PLATFORM OPTIONS

- Infra-red beacon tracking system
- TV camera & remote transmitter
- Additional STD bus card cage
- Additional power cage
- Additional DC-DC converters
- Head ultrasonic system

PAYLOAD PLATE OPTIONS

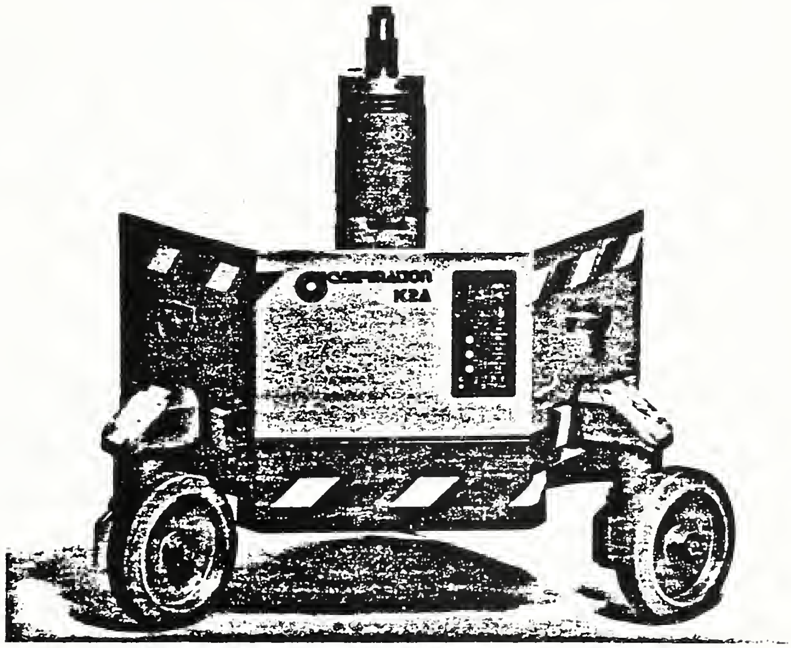
- Additional STD bus card cage
- Additional power cage
- Additional DC-DC converters
- Radio remote data link

Denning

Autonomous Intelligent Robots

21 Concord St., Wilmington, Massachusetts 01887 (617) 658-7800
FAX: (617) 658-2492

K2A MOBILE PLATFORM



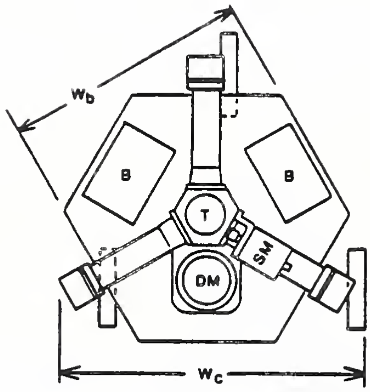
General: The K2A mobile platform is designed to provide mobility for autonomous, semiautonomous, and tele-operated robotic systems. The platform is fully self-contained, including motors, batteries, power amplifiers, and a control computer. The base uses a unique concentric shaft drive system which provides totally synchronous steering and propulsion drive to each of the three wheel assemblies. The drive system is completely sealed to allow operation in clean room environments and to reduce maintenance costs.

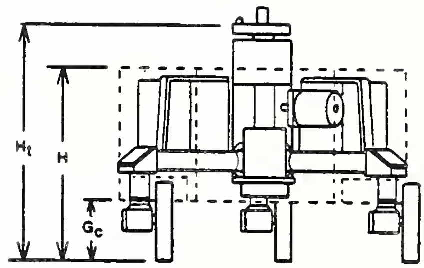
The "Synchro-Drive" system allows a single steering motor and a single drive motor to control all wheel assemblies in such a way that all wheels steer in the same direction at all times. Since all of the wheel driving forces are parallel, the robot exhibits excellent directional control on even the most adverse running surfaces. As an additional advantage, the base has no differential, as all wheels trace parallel paths. This eliminates the problems associated with limiting slip in a differential, and provides unsurpassed traction.

As a result of the steering action, the platform does not rotate as it executes a turning maneuver. Since the platform is likely to be the heaviest single component of the system, the energy required to accelerate and decelerate it rotationally is conserved. This is especially important in applications that require frequent turns. Furthermore, the platform has a zero turning radius, allowing it to operate in the narrowest possible pathways. Since it is usually desirable for the sensors of the robot to point in the direction of motion, a flange mount is provided at the top center of the platform. This flange rotates through 360 degrees in direct lock with the wheel assemblies. The user's "application turret" is normally mounted on this flange. An electrical connector at the center of the flange provides 24 volt battery power for the turret, and a bidirectional serial link with the platform computer. Using a simple protocol, the serial link provides total control of the platform as well as the capability of monitoring the status of the batteries, motors, and other subsystems of the platform.

Additionally, the link can access a dead reckoning navigation system that provides relative position feedback as calculated from wheel rotation. Because of the excellent directional stability and traction of the base, this type of position calculation is relatively accurate over short periods. In autonomous robots, information from this navigation system can be used to significantly reduce the search window of higher level navigation systems (sonar, vision, etc.), thus reducing the processing time and increasing the operational speed of the robot.

CYBERMATION 5457 Aerospace Road, Roanoke, Virginia 24014, 703-982-2641





SPECIFICATIONS

The following specifications are preliminary, and subject to change without notice.

Height: 20
Width (Clearance): 31.75 (See Table Below)
Weight: 310 lbs.
Payload: 250 lbs. max. continuous on level surface.
Drive Motor: 1 Hp P.M. servo
Drive Amplifier: 150 Peak Amp power FET PWM amplifier with torque fold-over
Steering Motor: .185 Hp P.M. servo
Steering Amplifier: 35 Peak Amp. 4 quadrant PWM amplifier, with torque fold-over
Turning Radius: 0.0
Rate of Turn: 120 degrees/sec.
Top Speed: 2.5 ft/sec
Acceleration: 0.1 to 2.5 ft/sec/sec
Batteries: 2-24 volt 65 AH sealed

NOTE: ALL DIMENSIONS ARE INCHES.

PHYSICAL DIMENSIONS

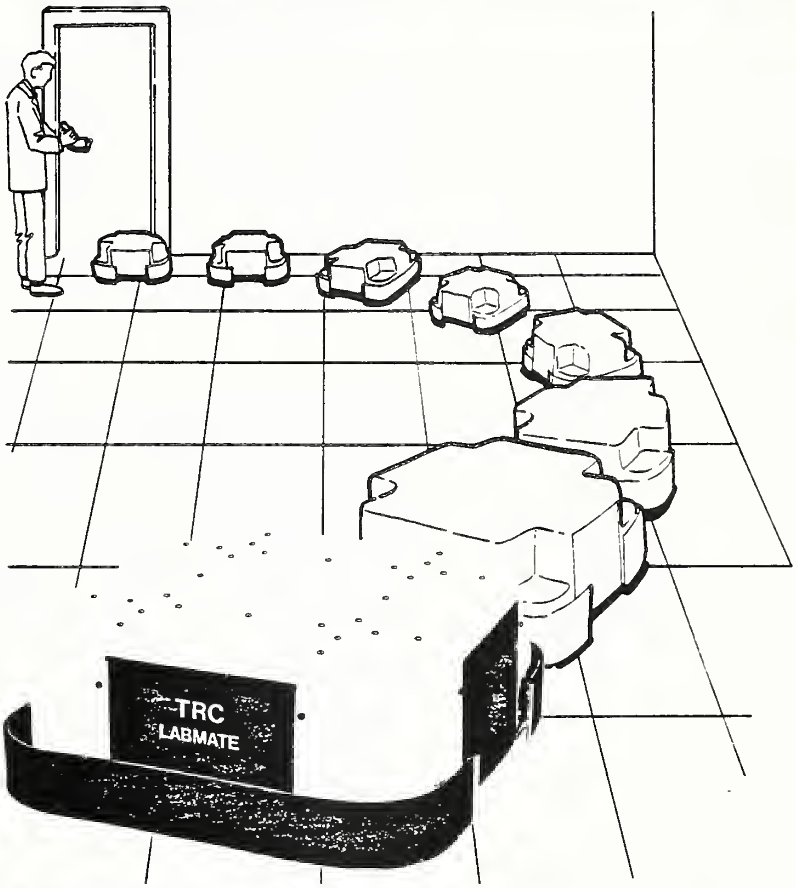
MODEL	LEG LENGTH	BASE WIDTH Wb	BASE HEIGHT H	TURRET MOUNTING HEIGHT Ht	WORSE CASE CLEARANCE Wc	GROUND CLEARANCE (APPROX.) Gc
K2A	10.000	24.000	20.000	27.125	31.750	5.500
K2A-1	12.000	24.000	20.000	27.125	35.000	5.500
K2A-2	14.000	24.000	20.000	27.125	38.250	5.500

NOTE: ALL DIMENSIONS ARE INCHES.

As shown in the table, the K2A is also available with extended legs for enhanced stability. Other options include weatherproofing, clean room fitting, and nuclear service fitting. For prices consult factory.

K2A 1.4 8/88

TRC



LABMATE™

Autonomous Mobile Robot Base

- eliminates the need to design or build an autonomous test bed for navigation research
- provides an off-the-shelf component for mobile products and systems
- operates under control of on-board microprocessor or optional joystick

TRC LABMATE
Autonomous Mobile Robot Base

SIZE:	11" x 27.5" x 29.5" (280 mm x 700 mm x 750 mm)
WEIGHT:	110 Lbs. (49 Kg.) (Less batteries)
LOAD:	200 Lbs. (90 Kg.)
SPEED:	0 - 40 in/sec (0-1000 mm/sec)
BATTERY:	24V (2 x 12V 40 AH or 60 AH batteries)
BODY:	High impact thermoformed plastic cover, over tube steel frame with multiple threaded inserts for mounting additional electronics or experimental equipment.
STEERING:	2 wheel differential steering on center axis with 4 passive casters and adjustable suspension.
FEEDBACK:	Encoders with .012 mm resolution per quad count.
DRIVE SYSTEM:	RS 232 interface, 9600 Baud 68HC11 based controls with 20 KHz PWM servos Open architecture to command: Velocity Straight Line Moves Turns, Zero to Infinite Radius Variable Steering for Sensor Based Control Programmable Acceleration Pause, Resume, and Emergency Stop Report Status
OPTIONS:	VME Card Cage 5V,+/− 12V Power Supplies Joystick Rate Gyro Proximity Sensors Warning Lights Battery Charger (Labmate sold without batteries) Batteries 12V 40 AH or 60 AH

Transitions Research Corporation • 15 Great Pasture Road Danbury, CT 06810 • (203) 798-8988

TRC LABMATE

LABMATE is a low cost, mobile robot base designed for use as a component in the development of transport systems and to support research in artificial intelligence, computer science, and robot engineering. LABMATE is a battery-powered vehicle with a complete control system which can carry up to 200 pounds of computers, cameras, arms, communications gear, or other application payloads.

LABMATE is designed for indoor laboratory or office environments. It can be driven on tile or carpeted floor and can clear the edges of carpeting or small obstacles up to 1/4" in height. LABMATE is sized to pass easily through doorways and corridors.

Inspired and partially funded by the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense, LABMATE is priced to meet the tight budgets of academic researchers and product designers while providing industrial grade component hardware that will give long years of useful service.

Mechanical Design

The mechanical design of TRC's LABMATE is shown in Figure 1. LABMATE has a "turtle" configuration with two powered wheels that provide motion and steering. Steering is accomplished by differential velocity control of the powered wheels. Four passive casters at the four corners of the vehicle provide stability.

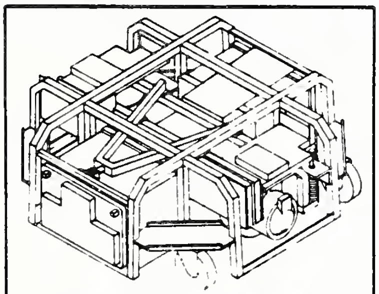


Figure 1 mechanical design

The drive wheels are mounted on an A frame suspension linkage. One point of the linkage is a ball joint fixed to the vehicle frame. The other two points are affixed to the frame by springs. The force exerted by the springs is adjustable for different payloads. This suspension design provides positive traction of the drive wheels on non-planar surfaces and allows the LABMATE to be driven over cables, small obstacles, sills, and the edges of carpet without losing control or position registration. LABMATE has clearance and power to negotiate a 10% ramp.

The drive wheels have the motors and gear boxes mounted integrally in the wheel hub. The hard rubber tires have a measured coefficient of friction on linoleum tile of 0.65. 1000 line encoders are mounted on the motors.

The frame of LABMATE is fabricated from welded tube steel with 40 threaded inserts to provide attachment points for sensors and payload. Battery compartments are adequate for 40 or 60 ampere hour sealed lead acid batteries.

The cover of LABMATE is a single piece of molded Kydex with four door panels for access to batteries and electronics. All interface points are brought to panels on the surface of the cover so the cover does not have to be removed for adding and integrating applications payloads.

Electronic Design

The controls for LABMATE are shown schematically in Figure 2. There are five main printed circuit boards that make up the controls: a general purpose computer board using the Motorola 68HC11 CPU, a piggyback dual channel servo control board with Hewlett Packard HCTL 1000's as the servo controls, two H-bridge amplifiers with Motorola SenseFETs and power converter card.

The HP servo chips provide for 20 KHz PWM servo control of the motors with proportional, trapezoidal, and integral control modes used for LABMATE.

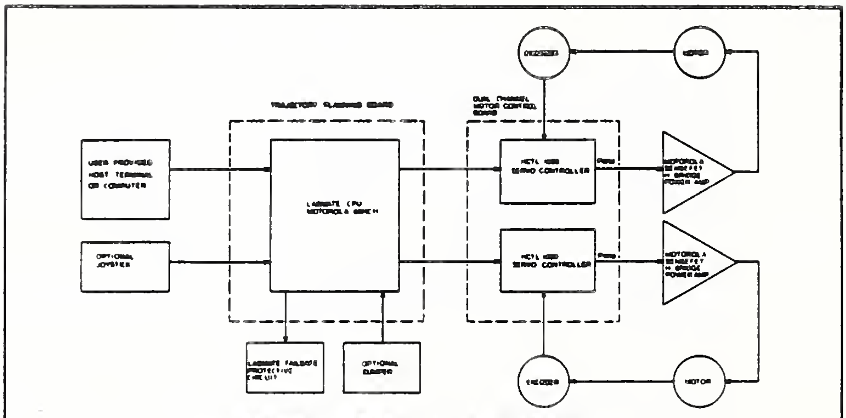


Figure 2 LABMATE controls architecture

Safety and protection circuitry includes an active watchdog monitor circuit, fuses in the power circuits, and contact sensitive bumper interlocks.

The LABMATE is designed to be controlled by a host computer through a 9600 baud RS-232 serial interface. A joystick for manual operation is an available option that is useful for moving LABMATE around the laboratory during development work.

Software Design

The vehicle control software is based upon the command set proposed by Professor James Crowley in his work with mobile robots at Carnegie Mellon University and at the University of Grenoble in France. The vehicle can be commanded to go a given distance, to turn a given angle with a given radius, or to initiate a commanded rate of turn. The first two commands are available in continuous path or point-to-point modes. The rate of turn command, or JOG command, is used for servoing the vehicle against higher level vision or proximity sensory feedback.

00 = Initialize System	21 = Enable and Clear Gyro Heading
01 = Enable Joystick Mode	22 = Set Watchdog Timeout Value
02 = Go (continuous)	
03 = Turn (absolute)	25 = Set Position
04 = Turn (incremental)	26 = Set Heading
05 = Go (point-to point)	
06 = Point-to point Turn (absolute)	33 = Read Position and Heading
07 = Point-to-point Turn (incremental)	34 = Read Wheel Positions
08 = Start a Continuous Turn	35 = Read Velocity
	36 = Read Status
17 = Set Velocity	
18 = Set Acceleration	49 = Emergency Stop
19 = Clear Position	50 = Pause
20 = Enable and Clear Encoder Heading	51 = Resume

Figure 3 LABMATE commands

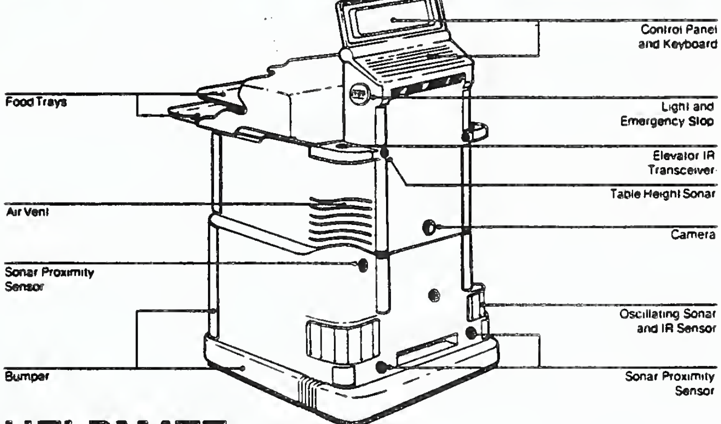
Figure 3 provides a list of the commands available with LABMATE. Each command is sent to the vehicle control computer as one byte followed by up to 5 bytes of data. A simple one byte hand-shaking sequence is provided.

All commands are specified in metric engineering units.

Safety features include a software watchdog monitor, bumper interrupt, external commands for E-Stop and Pause, and motor current monitors.

WARNING: ***The LABMATE should not be operated without safety bumpers and protection devices in place and fully functional. The user should read and understand all safety warnings in the*** **LABMATE User Manual** ***before operating the LABMATE.***

TRC



HELPMATE

Medical care costs in hospitals and long-term care facilities have been continuously rising. The employment of more costly personnel, the caring for sicker patients and the employment of more expensive technologies all contribute to these increasing costs. The successful implementation of robotic technology offers substantial reductions in operating costs.

TRC is currently developing HELPMATE, a mobile robotic nurses' aid, designed specifically to carry out mundane "fetch and carry tasks," now performed by nurses, aides and other support personnel. By assuming these time-consuming tasks, HELPMATE relieves highly trained personnel to carry out more critical duties.

Such tasks will include transport of:

- Special request meal trays
- Central Supply material and equipment
- Lab samples and specimens
- Pharmacy medication and supplies
- Patient medical records
- Administrative reports
- Contagious material/waste

HELPMATE uses vision, proximity sensors and dead reckoning to navigate through cluttered hallways, ride elevators and avoid people and stationary obstacles encountered along its route.

HELPMATE will be introduced as a product in 1988.

Preliminary Specifications

Size:	30" × 28" × 54" (750mm × 700mm × 1350mm)
Weight:	Approximately 350 pounds (160 kg)
Payload:	Approximately 30 pounds (15 kg) Standard and custom-designed payload compartments available.
Speed:	Maximum 20"/second (50 cm/sec) Greater speeds possible in controlled spaces
Power:	24 Volt batteries, 120 Ampere-hours
Body:	Welded steel tube frame with plastic covers Contact bumpers at base and corners
Navigation:	Vision and ultrasonic proximity sensors are used to understand the environment and avoid obstacles as they are encountered. HELPMATE can navigate from any point to any other point using a map of the building to plan the best route and using sensory feedback to follow that route.
Elevators:	Elevators can be modified to permit direct and independent control by HELPMATE, without inconveniencing human users.
Communication:	Computers and telephone systems can be used with HELPMATE's infrared communication links for central dispatching and reporting purposes
Safety:	Multiple safety features include non-contact obstacle sensing, contact obstacle sensing, emergency stop switches, flashing warning lights, interface to paging systems for emergency condition alert, and complete fail-safe controls design.
Availability:	Beta Test Site models available mid-1988 Production models available 1989
Contact:	Gay Engelberger Director of Marketing

Transitions Research Corporation • 15 Great Pasture Road Danbury, CT 06810 • (203) 798-8988

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NISTIR 88-4006	2. Performing Organ. Report No.	3. Publication Date NOVEMBER 1988

4. TITLE AND SUBTITLE

Assessment of Robotics for Improved Building Operation and Maintenance

5. AUTHOR(S)

Bal Mahajan, John M. Evans and James E. Hill

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report provides a state-of-the-art survey of robotic technology useful for building operation and maintenance. Floor cleaning, mail delivery, security, and storage facility operations represent current and near term opportunities for robotic application. Likely future applications may include: bathroom, office and window cleaning; lawn mowing; trash handling; wall painting; and miscellaneous material handling. Potential barriers to the use of robotics within buildings are identified. Amendments to the GSA Handbook on "Quality Standards for Design and Construction" to accommodate the use of service robots in Federal buildings are suggested. The suggested amendments are not exhaustive, and as our knowledge base expand these should be refined and augmented.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Barrier; building; floor; cleaning; delivery; mail; maintenance; operation; robotic; security; service.

13. AVAILABILITY

☒ Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

54

15. Price

$13.95