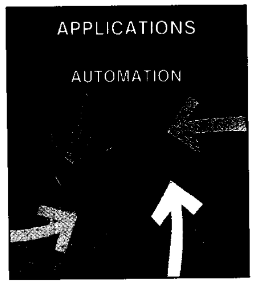
Japan robotics aim for unmanned space exploration

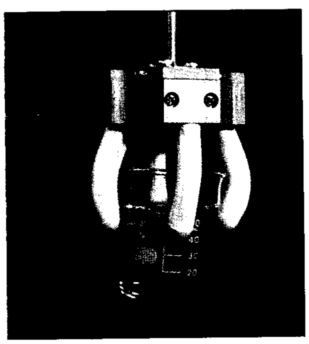
Government, industry, and university leaders have embarked on cooperative projects to develop next-generation robots for space

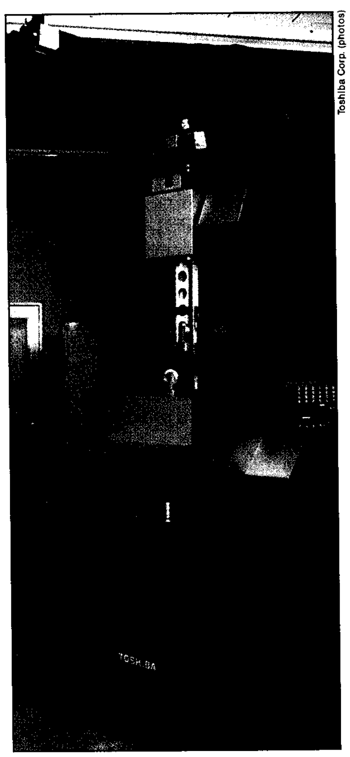


Last May, seven prominent U.S. roboticists crossed the Pacific to examine the latest Japanese research applicable to unmanned space endeavors. Their grueling schedule covered 30 facilities, but exposure to the latest Japanese robotics research—some of it quite innovative—was enthusiastically described as ample compensation. William L. ("Red") Whittaker characterized their intense immersion as equal to a master's degree. Their study, sponsored by the National Science Foundation and the National Aeronautics and Space Administration's Automation and Robotics Program, was prepared for the U.S. government's program evaluating Japanese technology. It is scheduled for release this month. What follows is an account exclusive to IEEE Spectrum *of the findings of the Japanese Technology Evaluation Center (JTEC) panel by its two cochairmen.*—Ed.

Japan's space program, though currently dwarfed by those of the United States, Europe, and the Soviet Union, has an unencumbered vision. It recognizes the enormous expense of manned space operations and intends to minimize this cost, as well as spur technology, by developing a range of automated machines.

The Space Robot Forum, a prestigious 70-member group from Government, industry, and academia, funded by the National Space Development Agency (Nasda), recently outlined an ambitious schedule for "third-generation" space robotics. Already, some very impressive and often novel work is occurring in industry and Government laboratories and Japanese robots are now employed in construction projects on land and under water, gaining experience that may be applicable in space. Although our JTEC study made no formal attempt to compare the status of Japanese and U.S. robotics research, it is clear that the United States could benefit in some areas by cooperative research with Japanese colleagues.





Toshiba Corp. (photos)

Rubber fingers (above), controlled by varying the pressure inside hollow segments, and a robotic arm akin to an elephant's trunk (right), developed for nuclear power applications, may find use in space. The fingers can even screw nuts onto bolts.

Some ambitious goals

Like many space powers, Japan plans to expand its frontiers and develop its own large rocket, shuttle, and space station, and explore the moon and then Mars. Many of the tasks will be done by machines, a progression from teleoperation (in which robotic devices are to a large extent remotely controlled by humans) to telerobotic operation (where robots do simple tasks on their own) to the third generation devices (where machines work without much, if any, human intervention).

The first launching of Japan's Hope Shuttle is planned for the mid-to-late 1990s. Hope is to be unmanned, but otherwise similar in function to the U.S. shuttle. Its main functions will be transport and serving as a platform for experiments. Also, Hope will dock with space structures and satellites.

As part of the Japan Experimental Module of the U.S. space station Freedom, planned for launch by NASA in the mid-1990s, Japan is developing a 9.7-meter-long robot arm capable of maneuvering a payload with a mass of 7000 kilograms. At the end of the long arm will be a smaller arm and gripper for more dexterity [see lower photo on opposite page]. Current U.S. plans include nothing like this mix of arms, which has a projected launch date of 1997.

The Space Robot Forum envisions Japan's own Cosmo-lab space station as an unmanned, low-earth orbit station assembled, operated, and maintained by earth-controlled robots [see photo, top right]. Among other things, it is to use a free-flying robot to tow satellites and cargo to the station, and a variable-geometry, or "serpent" robot with an arm of at least 25 meters. Six launches of Japan's H-II rockets, each capable of lofting 10 tons, should be enough to lift all the station components into orbit.

Although key technologies must be developed for Cosmo-lab and no funded work is currently under way on this project, the Japanese are likely to apply technology from first- and second-generation space robots and those developed for earth applica-

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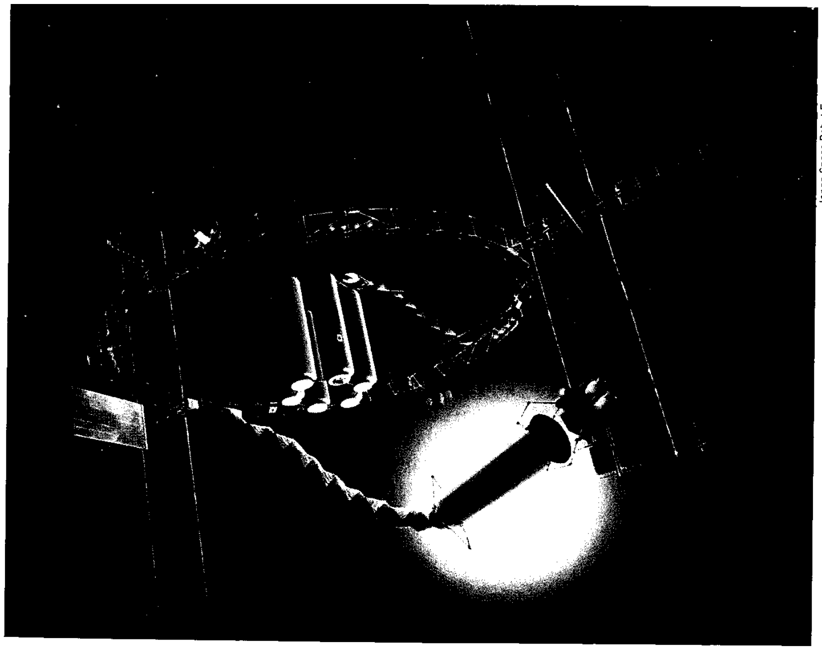
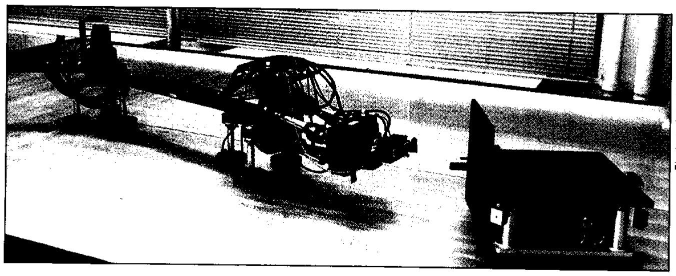
Japan's Space Robot Forum



Japan's Space Robot Forum, a prestigious 70-member group funded by the nation's space agency, envisions an unmanned space station with snake-like robots of at least 25 meters attached to a ring (right) and other machines that fly freely. Innovations for Japan's module on the U.S. manned space station Freedom include a long arm ending in a dexterous small armed manipulator (below).



Electrotechnical Laboratory, MITI

tions. Overall, Cosmo-lab has important implications for the future of space assembly.

Some 10 years from now Japan plans to launch an unmanned Orbital Servicing Vehicle to inspect, assemble, and repair satellites. Several concepts for the vehicle exist; key technologies, however, still need to be developed in sensing and perception, autonomous control, manipulation, and teleoperation. Eight organizations are working on the vehicle under Nasda's lead. In the mid-1990s, Japan will try to retrieve a special satellite by an unmanned "Space Flyer Unit." This should demonstrate techniques useful to OSV development, such as the coupled control of a free-flying vehicle and its manipulator.

Last May, Nasda announced a three-part lunar mission in which robots are to play a large role. Projected for launch in 2000, the unmanned Lunar Mobile Explorer (LME) is the first part of the mission. The 900-kg telerobot will investigate soil characteristics, collect and deliver samples, and determine whether water is present under the moon's permanent shadow. In the second phase, scheduled for 2010, the Japanese plan to establish a manned outpost mission. Settlement on the moon would constitute phase three.

Array of robots

The moon mission is the first where the Japanese envision roving about an extraterrestrial surface. Extreme environmental conditions—including wide temperature ranges, radiation, lower gravity, and rough terrain—will require a unique class of robots. These surface robots must move in hard or soft terrain, remain upright or be able to right themselves, and be physically self-contained in terms of power supplies, sensors, and computers. They must also be durable, highly independent of human control, and capable of exploration and construction.

Currently, the Japanese are not developing lunar exploration robots. But R&D for mobile robots does exist, stemming from areas other than space. Several combination wheeled-and-tracked robots, for instance, are in Japan's repertoire and more are on their way.

Mitsubishi Electric Corp., Tokyo, has a series of articulated track vehicles. The latest is the MRV3, which (like a child's dream toy) can metamorphose into any of three locomotion modes. In its wheeled mode, the robot drives in forward or reverse like any car. Also, by swinging its four wheels around the frame's corners (in the position of a car's front and rear bumpers), the robot moves sideways in either direction. Or, by moving the wheels to the corners of the frame, the robot can rotate in place.

To convert to mode two—the tank mode—the robot lowers four tracks 90 degrees so the tracks are horizontal. (In the wheeled mode, these tracks stand upright beside each wheel.) The robot can thus crawl up stairs or cross ditches. To switch to mode three—the walking mode—the robot lowers its tracks 180 degrees so they become four long stilts. Now it can stand high or stride over obstacles.

All three locomotion modes are accomplished using a newly developed drive mechanism of one motor, three shafts, and three clutches for each locomotion apparatus. If it can be adapted for hazardous environment work, the system may eventually be suitable for planetary exploration.

The Mechanical Engineering Laboratory of the Ministry of International Trade and Industry (MITI) at Tsukuba has developed an active suspension system that may find use in future space rovers. Its robot's four wheels rise and fall independently of one another with terrain. The platform is more stable over rough landscapes (and tips over less frequently) than traditional wheeled systems. For maintenance tasks within modules on a moon or Mars base, Hitachi's small, wheeled-and-legged robot made for nuclear power plants could be relevant.

Although most land animals move on legs, mechanical systems are far from approaching the great efficiency of horses and mules over rough surfaces. Though more attention has been devoted to wheeled systems, Japan is redressing that with some of the best research on walking robots with two or more legs. Their high maneuverability and efficiency make these robots prime candidates for planetary operations.

Japan's Port and Harbor Research Institute has been improving its Aquarobot over the last eight years [photo, p. 66]. It's a six-legged system teleoperated for inspection as deep as 50 meters under water (an environment with similarities to space). Other walkers include a Tokyo Institute of Technology quadruped that can move across uneven surfaces under autonomous control while keeping its body level [photo, p. 67], and Toshiba's small, crab-like robot for inspecting areas such as nuclear facilities.

Because of its dense population and limited land mass, Japan is exploring underground and undersea frontiers. Many of these technologies may be adaptable to space exploration and construction.

A seven-year project called Underground Space Development Technology began this year to devise technologies for building underground energy storage and supply systems, as well as cultural and commercial facilities. Already, Shimizu Corp., Tokyo, the world's largest construction corporation, has designed an automated excavator capable of digging a hole 3.2 meters wide and 150 meters deep. Another company, Komatsu Ltd., Tokyo, uses a huge, teleoperated robot underwater to level about 40 square meters of rubble each hour. The heights of the machine's legs are adjustable, and it levels large surfaces to an accuracy of less than 0.3-meter grade difference.

Shimizu has also formed a research team devoted to lunar base construction. Its scenario is to build a base on the moon using lunar materials and automated machinery. Plans call for the base to be a lattice of modules constructed from concrete produced on the moon. The concrete walls will be reinforced with cables to handle indoor air pressure. Extensive testing on the performance of concrete on the lunar surface has been undertaken by Shimizu and methods for hydrating the cement in the lunar environment are being developed. Construction of this base is to be performed as far as possible by robots, under teleoperation.

Some novelties

The JTEC team saw a number of novel mechanisms. Japan is already the dominant manufacturer of commercial robot arms for standard industrial assembly or transfer of assembly-line pieces. Its researchers are now developing more flexible manipulators akin to snakes, tentacles, or elephant trunks that hold great potential for space applications. Their long reach, narrow profile, and ability to conform to complex shapes allow such serpentine arms to, say, inspect pipe interiors or work on hard-to-reach components in nuclear reactors.

Perhaps the most comprehensive system is Toshiba's multi-jointed inspection robot [photo, p. 64]. It incorporates continued development in mechanics, sensing and control, signal multiplexing, and user interface. The arm consists of eight joints, each with two degrees of freedom, that are linked serially and decrease in size toward the tip of the "trunk." A low-weight actuation system uses components of titanium and composite materials. The arm is integrated with a mobile platform.

Other serpentine systems include Hitachi's nuclear containment-vessel inspection robot, Fuji Electric Co.'s 7.2-meter-long manipulator for nuclear inspection, and Osaka University's truss-type parallel manipulator. The segmented serpentine shape is also used for locomotion in robots, such as those at the Tokyo Institute of Technology [photo, p. 67].

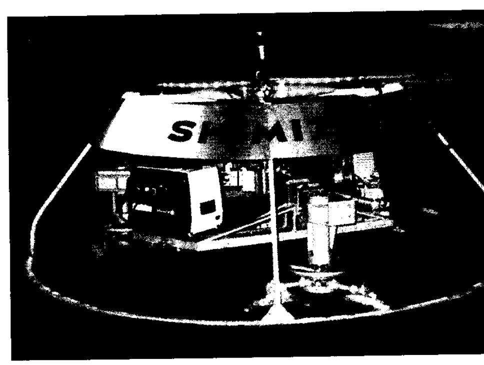
Toshiba has also devised some very interesting flexible fingers controlled with pneumatic servos [photo, p. 64]. Each finger is a hollow rubber cylinder divided lengthwise into three chambers that can be pressurized independently. By varying the pressures in each chamber, the pliant fingers can gracefully grasp a beaker from the exterior as human fingers might, or approach it from the interior and bend backwards to grip it. The main advance is the design of the cylinders to correctly repeat the movements as the pressurization changes and to stand up to constant pressurization. The fingers, controlled through joysticks without feedback sensors, can even remove nuts from bolts.

The Japanese have excelled in the development of focused, special-purpose systems, some of which may find applications in space. These include a ladder-climbing robot by Toshiba; a teleoperated live-powerline maintenance robot by Yasukawa; bipedal walkers developed by Tokyo's Waseda University; and Sesara, Matsushita's advanced two-arm torso that can stitch together a purse on a sewing machine, turn it inside out, and attach a shoulder strap. (Done crudely by human standards, this is state of the art with two-handed cooperation and sensory feedback.)

In addition, Toshiba has developed ARI, an assembly robot intelligent enough to study and complete an assembly task. A videotape shows the two-armed robot visually finding, grasping, and putting together Lego blocks without human intervention [photo, p. 67].

The move toward applications-oriented systems can also be

Kajima Corp.



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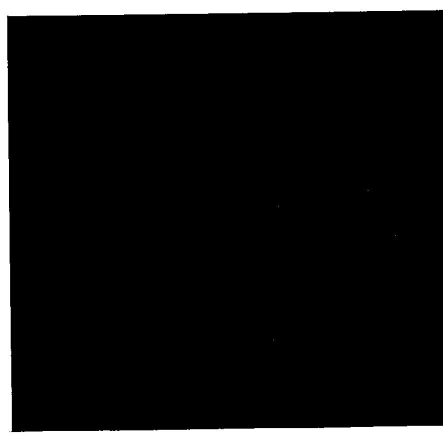
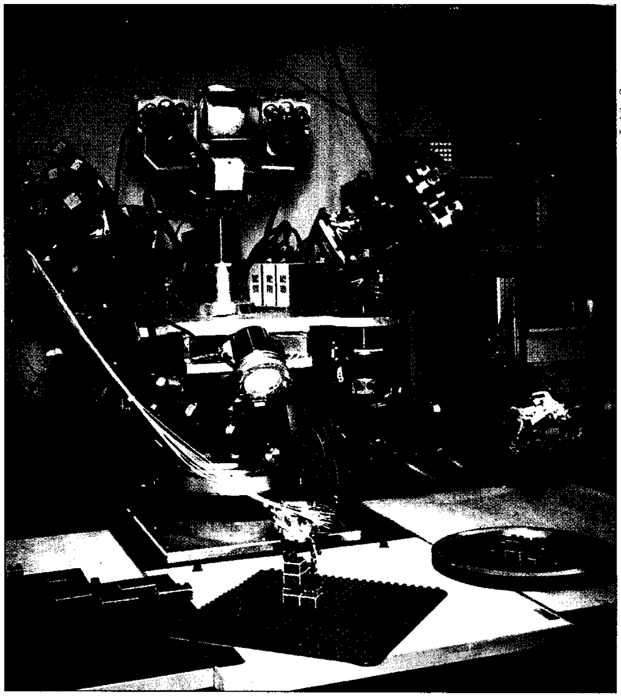


Port and Harbor Research Institute

Robots are already being applied in Japanese construction: to put up walls, smooth wet concrete floors, and check undersea foundations. Such tasks may be useful for automated construction on the moon or Mars.



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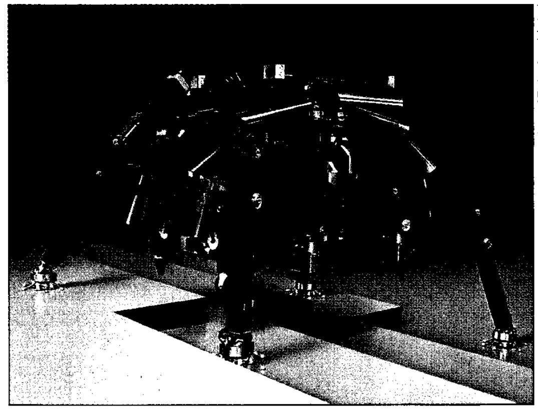
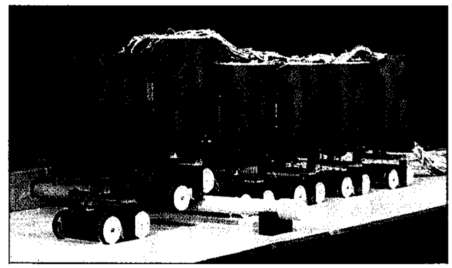


Tokyo Institute of Technology (photos)



Japan's impressive depth and range of research yields (clockwise from above) a two-armed torso for the study of assembly operations, a four-legged walking robot, and a caterpillar-like segmented machine.

seen in Waseda University's Breast Palpation Robot, which softly detects breast tumors with 25 sensors, and in Waseda's "humanoid" fingered robot, which reads music and plays a piano.

Looking far into the future, the Japanese feel that automation in space will be a huge enterprise. Thus they show a willingness to invest in long-term space robotics to develop a vast technological base from terrestrial work.

Quite a few companies that participate in space robotics have both a space division and an industrial robot division. These include Toshiba, Hitachi, Mitsubishi Electric Co., Fujitsu, NEC Corp., Mitsubishi Heavy Industries Ltd., and Kawasaki Heavy Industries Ltd. The first three companies build and maintain nuclear reactors, so they have additional incentives to develop robots for hazardous environments. There are also quite a few robot-user companies, such as Shimizu Corp., Komatsu Ltd., and Kajima Corp., Tokyo, whose skills may be useful in future space exploration or construction.

The Japanese Government's infrastructure for space development is analogous to the United States'. Various Government agencies—MITI, Nasda, the Ministry of Education's Institute of Space and Aeronautical Science—set policies, distribute funds, and determine the direction of projects. Private companies obtain contracts to develop systems. But, as in other areas, the Japanese Government often provides seed money and industry contributes significantly to the funding of research projects.

Since 1983, MITI has sponsored an advanced robotics program to devise a nuclear-powered robot, a subsea robot, and a disaster/firefighting robot. Twenty organizations (18 companies and two research laboratories) are collaborating. Next year, MITI plans to begin a "micro robots" initiative that may be relevant to space, and it is also considering a space robot initiative. During the JTEC visit, a MITI official proposed cooperating with NASA on space robotics, and the two agencies have begun discussing a joint project.

Since this was the first-of-a-kind portrayal of Japanese space robotics, overall, the JTEC space robotics endeavor should benefit agencies and researchers in both the United States and Japan. Possible future activities include similar studies for the United States and Europe/USSR, a biennial or triennial update of the Japan study, and cooperative or coordinated Japan-U.S. space robotics activity.

To probe further

The 263-page JTEC space robotics study to be published this month includes schematics, contacts in Japan, and references. To order, contact the National Technical Information Service (NTIS), 5285 Port Royal Rd., Springfield, Va. 22161; 703-457-4650. A videotape, spliced together from many facilities, highlights many robots described in action. It is also available from NTIS. Another, longer videotape, narrated by William L. Whittaker, is available for US $37.50 from University Video Communications, Box 20006, Stanford, Calif. 94309; 415-327-0131. For more information on Japan Technology Evaluation Center (JTEC), Loyola College, Baltimore, Md., contact the National Science Foundation, Washington, D.C.; 202-357-9498; or Duane Shelton, Loyola College, Baltimore, Md. 21210.

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