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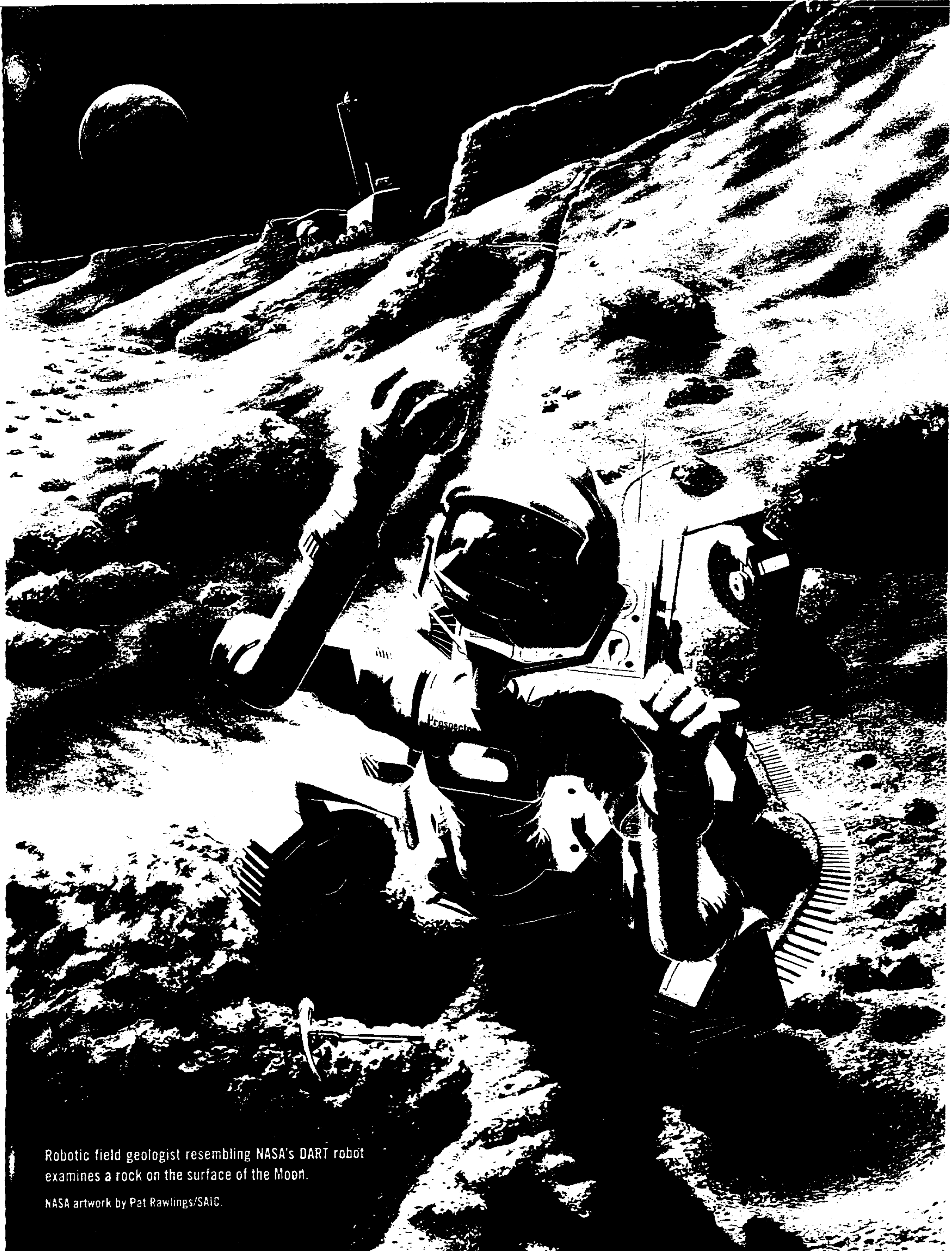
Virtual Presence: ONE STEP BEYOND REALITY

Robot Turns Planetary Geologist as Scientists and Engineers Team Up

By Nancy Ann Budden

A human is cloaked in a pair of wired gloves and a helmet seated in a rotating chair. As he slowly moves his hands an body, a large white robot behind him performs a slow grace ful mimic of his every motion. The robot grasps rock tongs picks up a rock from the floor and drops it into a sampl container, closes the container, and places it on a table. Th human operator performs as if in mime, without tongs, with out rocks, gloved hands empty. This demonstration take place in a NASA laboratory. Would this experiment work equally wel if the robot was hundreds of thousands of miles away, on the surface o the Moon or Mars?

The experiment described above is a demonstration of ful immersion telepresence, using a robot under human control to perforn routine geological tasks. But we are also witnessing the marriage of tw cultures, two areas of expertise—planetary science and exploratio working together with intelligent systems and robotics. Planetar scientists and robotics engineers at NASA's Johnson Space Center hav teamed up to study the feasibility of using virtual reality and telepresen robots to explore the planetary surfaces of the Moon and Mars. Thei efforts are focused on the specific capabilities and applications o



Robotic field geologist resembling NASA's DART robot examines a rock on the surface of the Moon.

NASA artwork by Pat Rawlings/SAIC.

a robot called "DART," the Dexterous Anthropomorphic Robotic Testbed, developed by a team led by NASA robotics expert Larry Li.

Planning Missions to the Moon and Mars

Mission analysts in the Planetary Missions and Materials Branch develop options for lunar and Mars missions that tell us where we are going, how we will get there, how many crew we need, what we need to take, and what we will accomplish on the surface. Such planning has in the past included the use of robots to conduct routine scientific tasks and explore planetary surfaces. Robots of this type require human operation (telepresence) and are thus highly interactive. These "robotic field geologists" may look like the *Star Wars* C3PO with a rock hammer, but in fact they are under full human control. NASA engineer Joyce Carpenter and I teamed up to answer the question: "Can DART really perform basic tasks of geologic exploration?"

DART creator Larry Li operates DART while draped in full immersion telepresence gear, consisting of virtual reality helmet, cyber gloves, arm wires, and audio command system.

Goal and Objective of the Study

Our primary objective was to team up a group of scientists and engineers from two different NASA cultures, and simulate an interactive teleoperated robot conducting geologic field work on the Moon or Mars. The information derived from the experiment will benefit both the robotics team and the planetary exploration team in the areas of robot design and development, and mission planning and analysis.

The Earth Sciences and Space and Life Sciences Division combines the past with the future contributing experience from Apollo crews exploring the lunar surface, knowledge of reduced gravity environments, the performance limits of EVA suits, and future goals for human exploration beyond low Earth orbit. The Automation, Robotics, and Simulation Division brings to the table the technical expertise of robotic systems, the future goals of highly interactive robotic capabilities, treading on the edge of technology by joining for the first time a unique combination of telepresence with virtual reality.

Geologic Exploration: Reconnaissance and Field Study

Exploration can be divided into two broad categories: *reconnaissance* and *field study*. Reconnaissance provides an incomplete but broad characterization of the geologic features and processes on a planetary body. It could include global geochemical and geophysical surveys, where large geologic formations and structures are identified and mapped into a global picture, at regional scales. Reconnaissance could be accomplished using orbiting satellite mappers and/or surface rovers, possibly in combination with human exploratory sorties.

The "closer look" of geologic field study attempts to understand geologic processes and units at all levels of detail, on local rather than regional scales. It involves studying and sampling the rocks in their natural environment, in a highly iterative process that may require repeated visits to the same site interspersed with rock analyses in the laboratory and revisions of the scientists hypotheses about the geological history of the investigation site as new information emerges. The course of study may be completely changed by the clues contributed by a single significant rock sample. Characterizing planetary surface features with such scrutiny will require some combination of highly intelligent robotic systems and human explorers.

Key elements necessary for geologic exploration are intensive work capabilities such as mobility, strength, manipulation, and the ability to perform both arduous and fine scale tasks. Of equal importance is the guiding influence of human intelligence and experience. Only humans can take brand new observations, integrate them into the brain's stored memory of geologic settings encountered in person and in study, and come up with a novel idea, or an integrated synthesis.

Geologic Robots: The Idea Emerges

Because many regions of a planet may be hostile or inaccessible for humans (too hot, too cold, too steep, too stormy), the idea of using robots to explore certain planetary sites is a desirable mission option. Paul Spudis of the Lunar and Planetary Institute and Jeff Taylor of the University of Hawaii were the first to suggest that one effective way to accomplish the goals of geologic field study on the Moon is through the use of teleoperated robots under the direct control of a human geologist who remains at a lunar base, in lunar orbit, or on Earth.

Using teleoperated robots has many potential advantages when the alternative would place human explorers in difficult and hazardous terrain. Robots could be built with a global traverse range and optical and sensory abilities optimized for geologic field work. This would allow the robot to chemically analyze a rock as soon as it encounters it, where the human would have to return the rock to a laboratory to run analyses later. Robots can possess physical strength superior to humans, and have the ability to work in a harsh lunar or Martian environment unencumbered by complex and massive life-support systems. Robots would also be less affected by radiation exposure and micrometeorite impacts.

Scientific discovery most frequently makes its greatest advances by the unveiling of the unexpected. Spudis and Taylor acknowledged that preprogrammed, fully autonomous machines were incapable of the on-site, spur-of-the-moment decision making necessary to change and revise an ever-evolving hypothesis of study. Human intelligence, experience, and interaction during planetary field work is an absolute necessity to explore the unexpected or never previously encountered.


Photo: NASA

DART dutifully mimics his operator's motions and chips a rock, this time in a lab, but perhaps, tomorrow, on the Moon or Mars.

Working with Spudis and Taylor in 1989, space artist Pat Rawlings painted a rendition of what a prototype robot field geologist might look like. Its coincidental resemblance to DART is uncanny. In fact, DART is very similar to the type of robot that future planners employ in their missions. For this reason, it is the perfect candidate to test-run exploration tasks, in an attempt to see just how difficult it would be to do planetary geology using telepresence.

Can We Really Do Robotic Geology?

Until our experiment, nobody had attempted to test just how capable a teleoperated dexterous robot could be. Can we realistically expect to accomplish ambitious geologic studies on an extraterrestrial surface using teleoperated robots? We decided to conduct a simulation of planetary exploration using an *actual* robot (DART), *real* state-of-the-art telepresence gear (Full Immersion Telepresence Testbed or FITT), *real* geologic tasks to accomplish, using *real* Apollo lunar geology tools, and *real* Earth rocks.

"Virtual Presence" Master and Slave System: FITT and DART

NASA project developer Larry Li describes his system as a "master-slave system." It combines robot telepresence technology with virtual reality, thereby coining the term "Virtual Presence."

The master, a human fitted with the FITT gear, provides operator control of the slave robot via the use of telepresence and virtual reality equipment. FITT consists of a virtual reality helmet for stereo visual feedback, magnetic sensors on the helmet and wrists to track head and arm movements, and two high-tech cyber gloves resembling fully wired racing gloves.

Once the human operator is draped in FITT, the DART robot will copy anything the operator does from the waist up. DART is not yet fully mobile, so the operator sits in a motorized chair which can rotate via foot pedals to spur a similar motion for DART. Anything that the operator can see through the helmet camera can also be seen and recorded by the robotics support team on an external video screen in the lab. The helmet is fitted with a microphone that transmits certain preprogrammed verbal commands to DART.

The slave, the Dexterous Anthropomorphic Robotic Testbed, is a human-like dexterous robot consisting of a stereo camera for a head, a rotating torso with two arms, and two "hands." One hand is equipped with a high resolution camera located under the thumb. DART can move this hand close to an object of interest for a close-up view. Voice commands from the FITT operator instruct DART to freeze, resume motion, or to switch camera view from head to hand camera. Functionally, DART is partitioned into six subsystems: arm, hand, head, vision, base and voice. Each subsystem is connected by Ethernet for communication. Sophisticated software sends information between the systems.

DART's highly dexterous hands have the eerie appearance and texture of human hands wearing rubber gloves. Each hand has 12 motors driving steel cables. The hands were developed by Dr. Ken Salisbury at Stanford and the Jet Propulsion Laboratory. The head subsystem consists of two color CCD cameras that provide stereo visual perception to the human operator. This subsystem also features a laser ranger on the camera to specify targets of interest and measure their distance from the robot.

Generating a Task Protocol for DART

Testing DART for geologic ability first required generating a list of tasks that would be likely for a robotic field geologist to perform on the Moon or Mars. These tasks fell into three operating categories: dexterity, tool operation, and optics and imaging. To evaluate dexterity, we asked DART to perform such actions as picking up and very slowly rotating several sizes and types of rocks, placing each in a sample bag, and closing the bag.

To assess tool operation we first gathered together a collection of geology hand tools. In an effort to simulate the equipment likely to be used in extraplanetary exploration, we selected the geologic field tools used during the Apollo missions. These include a rock hammer, rake, shovel, rock retriever (tongs), core tube, and gnomon (a color and orientation device). We also gave DART other non-Apollo items to manipulate, such as a flashlight, a iron analyzer called a Mossbauer, a sample bag, and a bucket full of rocks.

We asked DART to hold and move the flashlight, pick up a rock hammer and strike and chip a rock, pick up and operate a rake, hoe, rock retriever, core tube, deploy the gnomon, and pick up and operate a Mossbauer iron analyzer. Finally, to assess whether the optics and imaging were adequate for rock identification, we administered a rock test to DART. Very fine and specialized eye-hand coordination is required in a true field setting to examine rock samples at close range to differentiate their color, size, and subtle textural and crystalline features.

To conduct a fair test required that a "real" geologist actually wear the FITT telepresence gear, operate DART, and observe the rocks on his helmet screen. The test provided us the additional advantage of assessing how user-friendly the FITT exoskeleton and helmet would be to someone new to the system who had no prior training in telepresence. During the test our geologist was instructed to operate DART and select, pick up, rotate, and examine a dozen rocks and minerals. Like a first year geology exam, he was asked to identify rocks by name and mineral content.

Results of the Simulation

DART proved to be highly dexterous, capable of performing even the slightest movements with amazing accuracy and control. In addition to tasks assigned in our simulation, seasoned operators used DART to tie a knot in a rope, an arguably sophisticated task for virtual presence technology. Our experiment has encouraged us to pursue the use of robots as telepresent explorers, under the direct control of humans.

The robot was able to use a variety of tools, with very little time required to train operators unfamiliar with field geology techniques. DART was able to wield a hammer, chip a rock, place rocks in sample container baggies, and use rakes and shovels. The rock tongs were quite difficult to use at first, because of design idiosyncrasies specific to huma hands. However, like most of the Apollo tools we used i the simulation, DART would be able to use them more eff ciently with a few very minor modifications.

One area where DART needs improvement for planetai applications is in its optical system. The current camera sys tem lacks sufficient resolution to distinguish fine rock tex tures, color, and other features. In fact, the geologist was abl to determine only the most obvious rock types and mineral using both the head camera and hand camera views. Fo example, the geologist correctly identified a basalt sample but could not distinguish coarse-grained quartz or anothe sample containing large blood-red garnet crystals one-inch i diameter. One factor limiting the optics during the simula tion was the overhead fluorescent lighting in the laborator which subdues color and is too dim for rock identification.

We found that our novice geologist operators were able t learn to operate DART with a minimal amount of training usually two or three sessions. Sensory feedback would improve the system considerably, providing greater contro and the "you are there" advantage for the operator.

Applying DART Technology to the Search for Past Life on Mars

On 7 August 1996, NASA Administrator Dan Goldi announced that NASA's David McKay and colleagues ha detected tiny (200 nannometers) tubular structures tha resemble ancient fossilized Earth microbes in the 4.5 billion year-old Mars meteorite ALH84001. These features co occur with organic molecules and iron mineral characteristic of biological waste products. Together the evi dence points toward the possibility that microbial-like life existed on early Mars. Given that these microscopic features derive from Mars and presumably others like them still exist somewhere on the planet, future explorations of Mars wil most certainly focus on locating and sampling more of them Indeed, one of the top priority science questions for Mars before and after the advent of the ALH84001 findings remains: "Did life ever exist during Mars' Earth-like history and if so, is there still any life on Mars?"

However, going to Mars to find another ALH84001 will be difficult. We do not know where on Mars the meteorite originated although scientists have suggested possible sites of origin. We can, however, use our geologic knowledge of Earth environments, past and present, known to be hos pitable to microorganisms, and look for similar environ ments on Mars. Ancient Martian lake beds dating from a time when Mars was warmer and wetter, are considered to be one of the more promising sites to have quietly ponded and preserved microfossils.

Once targeted, areas on Mars such as the lake beds could be explored for past life. But how would we best undertake this mission? NASA's next robotic Mars missions, Mars Pathfinder and Mars Global Surveyor, have neither the objective nor the capability to search for past life-forms. Could DART technology be used to hunt for fossils in this scenario? Based on the current capabilities of DART, it is not a straightforward task. To immediately find and recog

Photo: NASA

Apollo 16 astronaut John Young performs field geology on the Moon, grasping a rock hammer with tired hands after setting up gnomon on lunar surface. EVA gloves and suits were cumbersome and awkward for delicate tasks.

nize fossilized evidence will be difficult for robots, and equally unlikely for human explorers. Rocks bearing such tiny structures are simply not going to appear any different than adjacent "barren" sediments.

Where DART would make its contribution in the search for life would be in the two areas of technical superiority and human participation. The search for past life will take a lot of slow, methodical field work, which translates into numerous long duration EVAs. DART has the capability to explore the harsh Martian surface in the worst conditions, for prolonged EVAs, posing no risk to human life. Where DART's direct optical capabilities would equal a human's, its ability to use imaging systems of differing wavelengths, as well as its strength and stamina, would far exceed that of human explorers. Further, the DART camera and arms could be equipped with spectral and Mossbauer-like analytical tools capable of differentiating mineralogies characteristic of ALH84001.

At any given time only one "master" can wear the FITT gear and "be" on Mars in a virtual presence mode. However, DART's observations would be simultaneously available in real time video to the best geologists and micropaleontologists the community could assemble. As experienced geoscientists "virtually" gathered clues to past Martian life, they could reconfigure the exploration strategy, constantly improving the potential for discovery. Working together through virtual presence, geologist and robot could symbiotically search for life on the Red Planet.

Future Research

Our first simulation compared the capabilities of DART with those of a human field geologist on Earth. Future studies will call upon NASA astronaut and Moon-walker John Young to compare DART's capabilities to those of a human confined by an awkward EVA suit and bulky pressurized gloves. Other upcoming work will explore possibilities for equipping DART with special sensors to analyze minerals in the field, or specialized cameras that can zoom and focus only inches away or miles from DART. We will further consider slight modifications to field geology tools that would make them easier to operate on an extraterrestrial planet surface. We will continue the quest to explore where no man has gone before. Using telepresent robots for some of the more dangerous areas, perhaps no humans will have to go into treacherous terrain at all.

Nancy Ann Budden conducted this research while at NASA Johnson Space Center; she continues this work as a Visiting Scientist at the Lunar and Planetary Institute. This article is LPI Contribution 875.