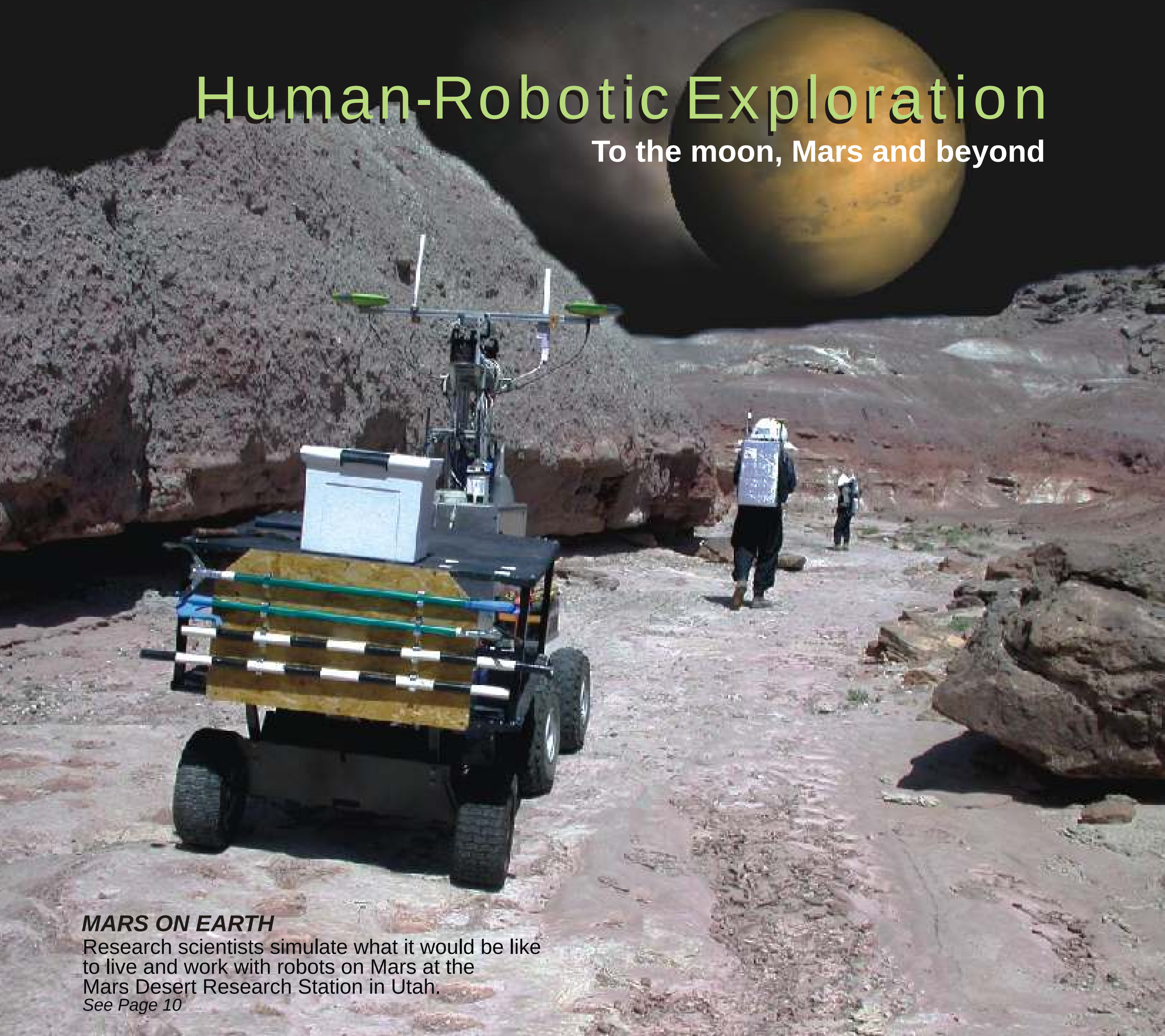
ir Intelligence Report

Human-Robotic Exploration

To the moon, Mars and beyond



MARS ON EARTH

Research scientists simulate what it would be like to live and work with robots on Mars at the Mars Desert Research Station in Utah.

See Page 10

A letter From the Division Chief

NASA Ames Research Center leads the agency in the development of advanced software and information technology capabilities and research. We perform mission-driven research and development to enable new system functionality, reduce risk and enhance the science return for NASA missions. Our technologies are implemented in mission operations, flown on spacecraft and aircraft, used by astronauts and adopted by other federal agencies. The depth and quality of our research is second to none.

As NASA's focus shifts to Exploration Systems, our expertise and capabilities become even more relevant to our missions. Complex new space systems, the Crew Exploration Vehicle (CEV) and teams of humans and robots working in space will all require advances in autonomous systems, mission operations, reliable software and data mining and discovery tools.

Just as the Computational Sciences Division's mature technologies have enabled the Mars Exploration Rover Mission to maximize its use of resources and to organize and share the data, information and knowledge gained in that mission, our new research will enable adaptive, evolvable and reconfigurable spacecraft and systems, peer-to-peer human-robotic teams, autonomous operations and enhanced crew reliability.

Exploration is not only about us reaching the new frontiers of the moon, Mars and beyond. It is also about the development of the technologies and approaches that will extend our senses and broaden our understanding of the vistas we explore. It is not about reliving Apollo's past successes, but exploring the new capabilities and technologies needed to enable our astronauts and robots to robustly explore, sustain a presence, understand the worlds visited, and bring that information home to Earth.

- Dr. Dave Korsmeyer

About Intelligence Report

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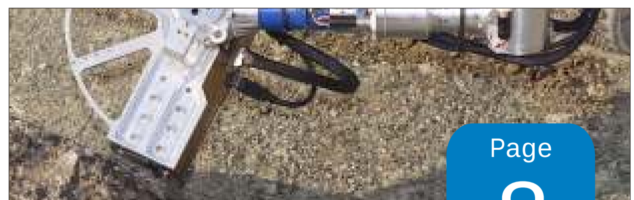

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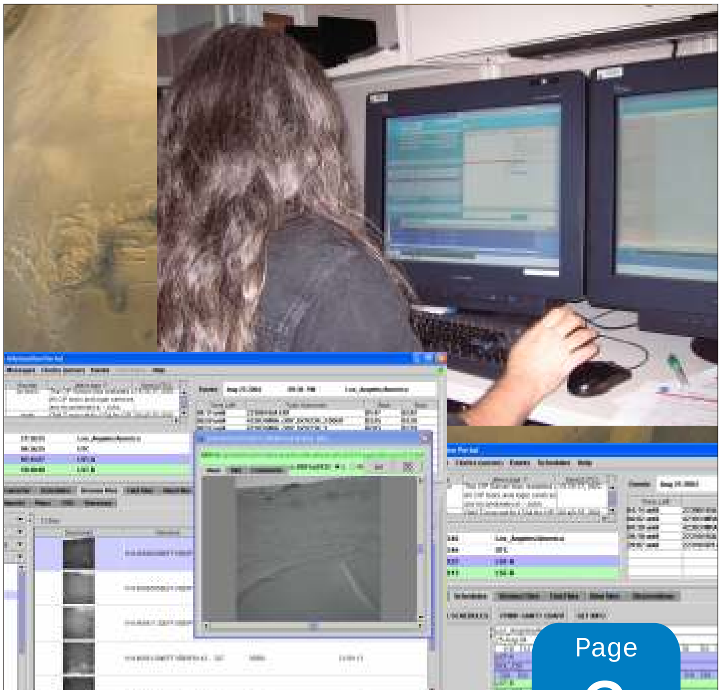

Also in this issue:

The Division's Exploration Research Areas

We provide leadership in information sciences for NASA by conducting world-class computational sciences research, developing and demonstrating innovative technologies and transferring these new capabilities in support of NASA missions and national needs.

Located at Ames Research Center, the division's approximately 250 NASA civil servants and contractors aim to enable a new era of human-robotic exploration. The division's research and development is extending space exploration capabilities through developments in human-computer interactions, autonomous spacecraft and autonomous robotics, reliable software systems, and information management and data analysis tools.

Reliable Software Systems

Our teams are developing and testing technologies that automate mathematical approaches for the analysis and generation of mission-critical software. These projects target sustained engineering, achieving affordable reliability over successive spirals of mission software development, and maintenance and upgrades for mission-critical software.

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Autonomous Systems and Robotics

The Vision for Exploration calls for closer cooperation between humans and robots than ever before. Creating robust robotic assistants as well as making other key systems on the Crew Exploration Vehicle self sufficient requires building systems that can adapt their behavior to environments that are complex, rapidly changing and incompletely understood. Ames Research Center has unique expertise and agency leadership in applying autonomy to NASA missions, developing the individual technologies required and integrating these pieces into autonomous systems for flight missions and terrestrial demonstrations.

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Integrated Systems Health Management

Integrated Systems Health Management (ISHM) is a strategic investment in sustainable space exploration. ISHM concepts and technologies may be applied to any complex engineered system such as transportation systems, orbital or planetary habitats, observatories, command and control systems, life support systems and safety-critical software. As an overarching design and operational principal implemented at the systems-of-systems level, ISHM holds substantial promise in terms of affordability.

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Mission Operations and Crew Assistance

Information technology has a dramatic influence on mission operations. Our key capabilities and research thrusts include human-centered computing, situational awareness and decision support systems, multi-modal interfaces and human factors, and complex information and knowledge management.

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To the moon, Mars and beyond

Advances in human-robotic exploration

President Bush announced in January 2004 the nation's Vision for Space Exploration. Space missions in the plan will require advanced systems and capabilities that will accelerate the development of many critical technologies.

While the Computational Sciences Division is continuing its landmark research in robotics, autonomy, communication networks and systems and information management, the division is focusing on future human and robotic missions. To meet the Nation's exploration goals and objectives, we're advancing technology within NASA and through strong partnerships with private industry and other government agencies. Here are the initial intramural proposals funded at Ames by NASA's Exploration Systems Mission Directorate (http://www.exploration.nasa.gov).

A Plug-and-Play Architecture for Intelligent Avionics

Future spacecraft, rovers and other robotic platforms will need onboard intelligence and computing that will adapt to unforeseen events and failures. The plug-and-play Guidance, Navigation and Control (GNC) architecture we are developing is being built around a neural network that will generate command signals to compensate for errors due to failures, model changes or other causes.

The GNC architecture will be designed around Field Programmable Gate Arrays (FPGAs), programmable devices with reconfiguration capability that can be used for fault recovery or performing multiple tasks. FPGAs are already used extensively in space applications.

The current version of this control architecture is scheduled for flight tests on an F-15 at NASA Dryden Flight Research Center.

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Automated Design of Spacecraft Systems

Advanced software techniques that automatically design and optimize hardware and software will enhance NASA's performance while saving the agency significant amounts of time and money. This research will develop, test, validate and deliver automated design algorithms that target specific applications for future exploration missions, yet will add broad common value across NASA missions.

The techniques, Evolvable Systems, are creative algorithms sometimes termed invention machines because they can produce patentable inventions. One example from an Evolvable System is an antenna Ames Research Center produced for the Space Technology 5 (ST5) mission. The antenna has an unusual, organic structure, and outperforms an antenna that was designed conventionally to meet the same requirements. When ST5 launches, the antenna will become the first evolved hardware ever flown on a NASA mission.

Evolvable Systems methods include genetic algorithms, genetic programming, artificial neural networks, simulated annealing and variants.

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Embedded Advisory System for Crew-Automation Reliability

Mental fatigue, cognitive overload, sleepiness and space sickness are examples of cognitive states that impair a crew member's judgment and performance. Because crew members try their best to compensate for these states with increased effort, their performance does not immediately degrade. But the risk of error does increase, and often these states do not become evident until errors or response delays have already threatened mission safety. The ERTAS project (Embedded Real-Time Advisory System for Crew-Automation Reliability) will reduce the risk of errors and response delays by developing advanced sensors and intelligent software to detect and counteract error-prone states in individual crew members. ERTAS will provide three kinds of error-mitigating feedback: advisory information and warnings, context-dependent cognitive aids such as checklists and memory aids, and trigger signals to automate system functions or actions. For example, if ERTAS signals inattention or decreased alertness, the salience of visual or auditory icons may be increased. Successful technologies will be embedded in command, control and communications systems for human-robotic teams, with a focus on tasks that are vulnerable to effects of cognitive fatigue and overload. The output of ERTAS will be most useful for demanding or prolonged tasks that require human performance or supervision, such as telerobotic control, or IVA and EVA for in-space assembly and maintenance.

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Fully Automated Operations: A Trade-off Assessment

This research will bring together for the first time perspectives on autonomy, robotics, mission operations and human-centered computing to provide a basis for assessing the role of autonomy in exploration.

Two existing rover platforms will provide data.

The Mars Exploration Mission rovers will describe time-delayed interactions between engineers and scientists on Earth and robotic task execution on Mars.

Carnegie Mellon University and NASA use a rover with a “sliding autonomy” control system to search extreme environments on Earth for evidence of present and past life.

The rovers will provide mission operations scenarios for surface operations consistent with the exploration agenda and will conduct field campaigns to validate the analytical model and test its applicability to the design of future missions.

The project team will use the rover data describe the trade-offs involved with three factors on which automation of robot-human interaction depends: the capabilities and robustness of the technology, the economics of implementation and the best use of mission personnel in the command-and-control loop.

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Peer-to-Peer Human-Robot Interaction

Developing robots to perform tasks such as assembling and maintaining spacecraft and habitats will be a key to successful lunar, planetary and space exploration.

This research will develop a human-robot interaction operating system that will enable robots and people to work effectively together. The teams will communicate using multiple modalities of communication, including speech and gestures, whether side by side or on different planets. This research will focus on semi-autonomous robots for interaction. The research team will develop a range of human-robotic interaction techniques and technology so that robots can work as partners, individually and in groups with their human peers.

The team’s approach has three components:

The robot will be able to ask questions to compensate for limitations or failures in autonomy, and we will investigate techniques to determine how and when it is appropriate for the robot to interrupt local and remote humans.

Computational cognitive architectures will be used to model human behavior so that robots can reason about the behavior and knowledge of their human partners.

Structured field tests will assess system and human and robot performance, taking advantage of numerous human-scale surface rovers and the microgravity testbed at Ames.

The SeguaNaut Robonaut-on-wheels robot system will travel from JSC to Ames for our field trials.

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Trade Study on Autonomy for the CEV

One of the fundamental challenges of designing and operating NASA’s planned Crew Exploration Vehicle (CEV) will be to reduce the current mission dependence on large ground teams. Projects are under way to develop intelligent devices and systems that require less human monitoring and control. But accurate determinations of how and when to incorporate autonomous or semiautonomous systems will be crucial to their safe and effective use.

A key decision to be made in the design of operational concepts is whether systems such as power, propulsion, navigation and life support should be monitored and controlled by the flight crew, by onboard autonomous systems, by ground crew or by ground autonomous systems. A team at Ames is working with collaborators at JPL and JSC to study current work practices in space shuttle and International Space Station operations, and then estimate the effects of bringing more automation into these processes. This data will help NASA set priorities and create processes, tools and models as the CEV is developed.

The results of this study will allow NASA to apply autonomy where the benefits would be greatest and where the costs and risks would be least.

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Reliable Software Engineering

NASA’s exploration missions will increasingly rely on highly capable software to achieve greater levels of autonomy and robustness. This research is a technology-based means for achieving software reliability and affordability for software development, verification and sustained engineering.

The project will deliver three capabilities for reliable software engineering that span the software lifecycle: automated testing, hierarchical software integration for validation and verification, and scalable program synthesis and code-level verification. It will scale individual technologies from effectiveness at the component level to effectiveness at the system and system-of-systems levels through algorithmic integration, achieving capabilities that no technology can deliver by itself.

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Mission Tools

Ames and the Mars Exploration Rover Mission

A Mars Exploration Rover (MER) Mission rover science team member says that an automated ground-based decision support system developed at Ames Research Center helped MER science teams build plans that on their most difficult scheduling days enabled up to 50 percent more science activity to take place on Mars. The system, MAPGEN, takes into account hundreds of flight rules and resource constraints, more than a person can comfortably handle, as it automatically generates a plan.

“I don't believe a human being could get the efficiency out of the process and pack it that tightly and satisfy all of the flight rules,” said Larry Soderblom of the U.S. Geological Survey, who has been involved with about a dozen NASA missions including the 1997 Sojourner rover mission. “In complicated cases, we might have lost 30 percent, maybe even 50 percent of the mission.”

JPL selected MAPGEN (Mixed Initiative Activity Planning Generator) and another Ames computer science tool, the Collaborative Information Portal (MERCIP), for use during the extended MER mission. MERCIP is a staff scheduling and knowledge management tool that provides easy, customized access to the enormous amount of mission data.

“I can't imagine doing a mission like this without something like CIP,” said George Chen, flight director for the Mars Spirit rover.

MER was initially scheduled to end in May but was continued because the rovers were healthy. The MER Project at JPL is funding the extended mission use of both tools.

The MER mission is the most complex planetary surface exploration mission NASA has ever attempted. For mission staff, each day is a race against the clock while teams analyze both the previous day's and incoming data, select science goals for the next day, build an activity plan for achieving the goals, then put together a sequence that tells the rovers exactly how to accomplish the goals.

MAPGEN

MAPGEN enables the mission’s human planners to effectively perform their jobs under the mission’s tight time constraints. Ames’ John Bresina is a MAPGEN developer. During the first six months of the MER mission he used the tool daily to include as many of the science teams’ requests as possible.

In some instances, said Bresina, late-arriving rover data had signaled that a completed plan was unsafe or infeasible for the rover to carry out. Had the staff been manually handling the data instead of using MAPGEN, they would have been forced to cancel the next day’s science activities. But MAPGEN enabled the staff to quickly redesign the plan and still meet the daily rover uplink window.

“One of the biggest advantages of the planner is that you were able to respond to those big changes," Bresina said.

MAPGEN is a mixed-initiative system. With MAPGEN, the human user is in control, guiding and monitoring the progress of the tool’s automated reasoning methods and overriding them if necessary.

JPL’s Jeff Norris, also a MAPGEN user responsible for integrating science goals into a daily activity plan, says he uses MAPGEN for “what-if” analyses. “It helps people experiment with other alternatives for a science plan.” But most importantly, Norris said, the tool lets him know if he’s violated a flight rule, such as scheduling two activities at the same time that would exclude each other. “It was a relief to know that it was watching.”

MERCIP

“Almost everyone in the mission uses CIP,” said Joan Walton, who helped lead the tool’s development at Ames.

CIP is a suite of tools. A popular feature is its schedule-viewing tool that broadcasts events and personal schedules in real time. That’s important when 240 people are working around the clock to navigate two rovers on opposites sides of Mars, a planet with a 24-hour, 39-minute day. The schedule information comes from many sources and it changes constantly. By using CIP, the mission staff keeps up with these changes and meets deadlines during the hectic operations schedule.

In addition, data navigation tools enable users to find reports and plans, search for them and subscribe to the latest data coming from a rover or a mission staff meeting. Access to mission data is greatly simplified with CIP. A user with a wireless laptop has the same data access as a flight director using a sophisticated work station. Team members can quickly and reliably access information from anywhere, including the mission control center, offices or home institutions.

“I'm very proud of how reliable the system has been,” said Walton.

MERCIP project manager John Schreiner plans to further develop CIP for future missions. Discussions with flight operations and science teams are under way to broaden CIP’s tool sets and capabilities.

Mars Science Laboratory

MAPGEN is being considered for use in the next rover mission, the 2009 Mars Science Laboratory (MSL), which involves an ambitious plan for increased robotic capability. The Computational Sciences Division is working with JPL and MSL managers to design and develop a software system for MSL.

MSL calls for a system that will enable the rover to plan and schedule its behavior, execute the plan, monitor and respond to its system health and safety and pay attention to resources such as time, memory and power.

The MER uplink system is excessively manual, requiring many people. MSL calls for reducing the number of people and the number of steps involved, thereby improving the efficiency and reducing mission costs. The Ames-JPL team is working to streamline the uplink process.

The centers are also working to design and develop MSL technologies that will enhance a rover’s data collection and analysis capabilities, reduce costs associated with debugging mission software and enable close collaboration among scientists and engineers working anywhere in the world.

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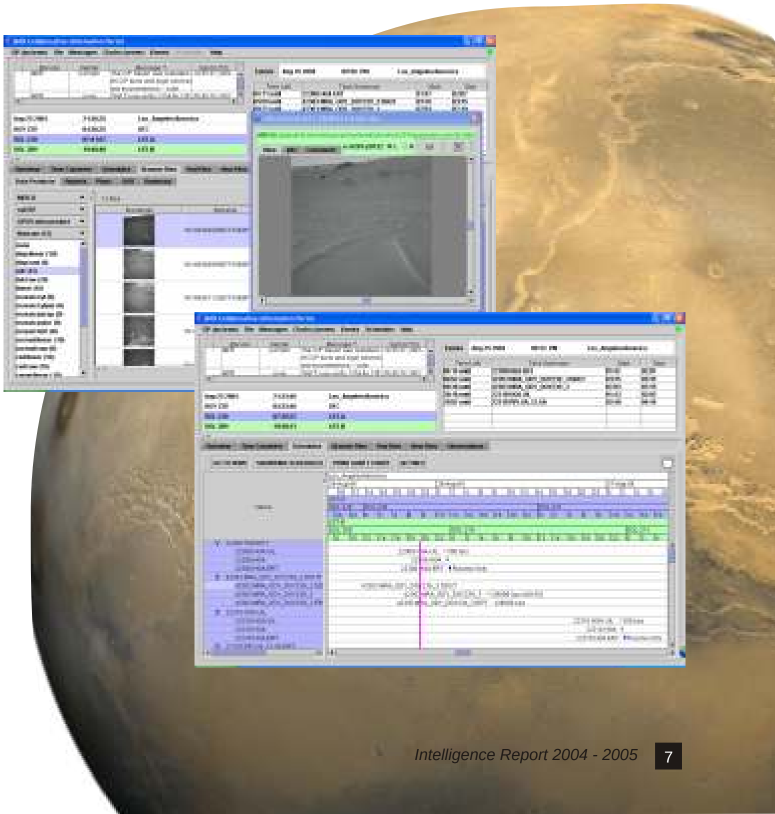

SCIP

Single Cycle Instrument Placement

Current state-of-the-art planetary rovers need two to three days and the assistance of hundreds of scientists and engineers to determine a rover's science target and command the rover close enough to the target to take a sample.

Single Cycle Instrument Placement (SCIP) enables a rover to approach and place a science instrument against a rock or other science target in a single command cycle. The project is building the capability for a rover to visit and examine multiple targets over many meters, unsupervised, and in an unprepared environment.

Using the test rover K9, a six-wheeled, solar-powered vehicle, researchers in 2002 and 2003 successfully demonstrated SCIP. The next test includes a team of geologists that will determine goals for the rover to execute.

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Contingency Planning Software Automatically Anticipates Plans for Contingencies

One of the biggest inefficiencies with the Mars Exploration Rover Mission's approach to handling uncertainty is dead time. A rover that cannot carry out a human-generated plan shuts down until support teams build and uplink a new set of commands the next day. A day lost can cost millions of dollars, and valuable exploration time.

Ames Research Center is addressing the problem with contingency planning software that automatically anticipates and plans for possible contingencies. For example, if a rover uses more energy than expected to reach a given science target, the plan might specify an alternative science objective or alternative target.

The contingency planning software system starts with a set of science goals developed and prioritized by science teams. The software builds a plan to achieve the highest priority goals given the expected resources available, such as time and energy, and the expected consumption of those resources by the actions involved.

The system then evaluates this plan to determine what might make the plan fail, given uncertainty in the time and resource consumption of the actions. Using this information, the planner considers other feasible science objectives, and introduces contingency branches into the plan wherever possible to handle the potential failures. The planner is able to determine under what conditions doing something other than the primary plan would be useful.

Contingency Planning software is being tested on the K9 rover at Ames Research Center, as part of the Single Cycle Instrument Placement project.

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SCIP includes a suite of software that represents advances across a broad technological front

Execution:
Onboard the rover, the conditional executive is able to consider a number of alternative conditions while it executes a plan. The software directs the rover to drive to sets of targets, deploy science instruments and take measurements. Along the way, the software monitors the rover's consumption of resources, can spot danger or opportunity, and will select an alternative plan.
Contact Howard Cannon:
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Problem solving:
Model-based fault management will maintain a vehicle's health and safety by detecting, diagnosing and solving problems. For example, while a rover explores Mars its software might monitor its wheel speed and the battery's current draw. If the software determines that a wheel is spinning unintentionally, say, the software will try to solve the problem, perhaps by telling the rover to back up. Or the software can contact mission control for help.
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Navigation:
To approach the designated science target without help from mission control the rover must keep track of the target as it navigates. The rover uses images from its stereo cameras to build 3D models of the terrain as it drives. Using a technique called 3D model registration to compare and align the models built before and after moving, the rover can determine where it is in relation to the target.
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Seeing Mars
A software package called Viz uses the two-dimensional images a rover returns to Earth to display 3D pictures of the martian environment. With Viz, teams can measure the rock surface areas and the distances between the rocks with clicks of a mouse. The software predicts when and where on Mars the sun will cast shadows so that mission planners can capture good images and data.
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The framework:
CLARAty is a software framework that essentially bolts together the many other pieces of software that are controlling the rover and enabling people to interact with it. CLARAty is unique in that it works on many different robots, and enables researchers at multiple institutions to build on each other's work. CLARAty is a joint project of researchers from JPL, Ames and Carnegie Mellon University, among others.
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The K-9 rover testbed at Ames Research Center

Mobile Agents

Spring 2004

In the orange rocky desert of southern Utah, a group of scientists and engineers is simulating what life and work will be like on the dry desert planet of Mars. Ames Research Center is taking part in a Mars Society Mars Desert Research Station (MDRS) mission, two weeks in a two-story metal habitat in Mars-like conditions.

To simulate working on Mars, while conducting biology and geology field exploration, the Earth-based desert crew members wear space suits and coordinate with robotic assistants and all-terrain vehicles. The goal is to learn how to automate many tasks that are involved with lunar and planetary surface exploration, and to determine what skills, technologies and work systems are needed for a safe, productive human mission to Mars.

Scientists, Robots and Vehicles are on the Multi-Agent Team

Mars habitat simulation uses human-robot coordination

Two geologists wearing white space suits move slowly down a rocky path. Each is wearing a helmet and a backpack equipped with a wireless communication system and a field geologist's tools.

In the canyon, the pair separate to study the cliffs. The geologists are using what's called the Mobile Agent system to conduct science, talking with the computer software and each other about their science observations.

One of them picks up a sample. Using his voice he names it, then records his location and a note: "That looks like petrified wood."

In the canyon, behind the team, a robotic assistant moves autonomously to several spots, sending images to scientists working in a habitat a half mile away. As the wheeled vehicle records images, it logs its location.

Watchful eyes

A group of computer scientists is watching attentively, looking for ways to describe the teamwork that is necessary for the geologists to do their jobs, and how future technology can help facilitate that. During the field test the crew is experimenting with different types of human-robotic collaboration, and with mission operations work systems and technology.

"During Apollo missions to the moon, astronauts continuously talked with mission control in Houston. You can't have that kind of communication on Mars," says William J. Clancey, principal investigator for the Mobile Agent software project at NASA Ames.

During future planetary exploration on Mars, Clancey says, data might be relayed by personal agent software to others on the science team, both on the planet's surface and back on Earth. Information could be stored in a database in a planetary habitat, and the software could send it to scientists who are collaborating from Earth.

Mobile Agents system

Computer scientists at Ames developed the Mobile Agents system, which uses a multi-agent, distributed architecture that integrates diverse components in a voice-controlled EVA communications and astronaut assistant system including biosensors, cameras, GPS, JSC's EVA Robotic Assistant and a science database.

The system integrates a number of Ames software projects: modeling software Brahms, spoken dialogue system RIALIST, wireless network Mobile Exploration System and Web-based information management system ScienceOrganizer.

The Mobile Agents system partly automates the role of mission control, gathering data and communicating to the habitat and to mission control and monitoring EVA navigation, scheduling, equipment deployment, telemetry, health tracking and data collection. The system includes a wireless infrastructure for monitoring and managing science, data collection and processing.

"We're building a workflow system," says Clancey, who is serving as commander of the desert station crew, "automatically routing the data and the scheduling information to all the parties involved."

The Mobile Agent software correlates the GPS position data with a location name so that any images or samples taken there are correlated with that location name. "It provides context for observations," says Rick Alena, who is leading the wireless system research and management.

Mission safety

The system also is monitoring "astronaut" health, and sends their commands to robots, vehicles and mission control.

In addition to using the system in this manner, the astronaut explorers can tell the agents what activity they are going to do next. The astronauts choose activities from a menu of potential planned subjects. If the astronaut deviates from the plan or the planned location, or stays too long, the personal agent software will verbally warn the astronaut.

At the same time, the computer agent will send e-mail to the support team on Earth and to another computer agent in the habitat, which will announce on the habitat's loudspeaker that there is a possible problem.

The robot can work alone or with geologist gathering rock samples, serving as a mobile supply cache and recording a geologist's voice notes, such as the description of a geological sample, with location and images, all the while following the geologist's commands.

The MDRS mission is an ongoing simulation of the Mars Society. Ames researcher Maarten Sierhuis is managing the Mobile Agent-robot test that will includes at least a dozen other researchers.

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Mobile Agents System Technology and Research

The Mobile Agents system is transmitting data and assisting with communication between crew members working outdoors, the crew in the habitat and remote mission support teams. The Mobile Agent software is using the models of robot-crew interaction and the work practice of the scientists to enable the scientists to conduct effective science surveys.

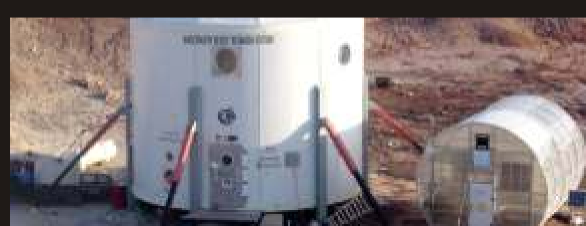
A software system called Brahms is modeling human-robot interaction taking place in the field. It is being used to build models of the work systems in the field and in the habitat. Researchers use Brahms models to simulate mission scenarios to determine a mission's effectiveness, as measured by science return and safety.

Speech recognition software RIALIST is acting as the interface for the astronauts to issue commands to the Mobile Agents system. While working, the crew is telling the system which activity they are executing. This is setting expectations of their location and the time they need to carry out the activity.

Mobile Exploration System (MEX) software is the host infrastructure for the Mobile Agents software. MEX consists of computers carried in the astronauts' backpacks, computers on the all-terrain vehicles and hand-held graphics tablets. MEX elements are connected via a complex hybrid wireless network consisting of a backbone with local clusters. The GPS data is associated with photographs, samples and activity timelines to provide context for scientific observations.

This year groupware tools are providing data access to the remote science teams and facilitating their collaboration in formulating plans with the crew. ScienceOrganizer is a semantic data repository the crew is using for the field simulations. Remote science teams are using it to access data and to interact with the astronauts in the field.

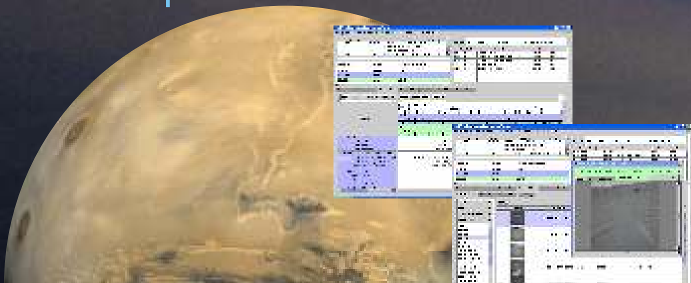
- NASA Research and Education Network is providing satellite services and Voice over IP telephony for field simulation support. This group is conducting network monitoring and analysis for optimization of the system.

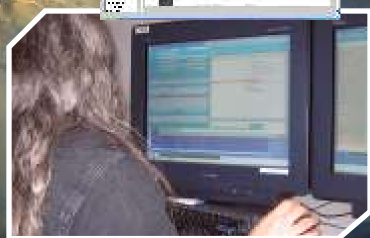


Computational Sciences Division

Current software demonstrations in the field, in flight and in space

Mars Exploration Rover Mission Extended Operations





MERCIP

collaborative information-sharing tool provided mission staff with situation awareness and one-stop access to mission data

MAPGEN

mixed-initiative planning and scheduling tool significantly increased science return and mission safety with automatically generated plans

Analog Field Campaigns

Mars Desert Research Station

developing and testing a complex multi-agent software and hardware infrastructure to support humans and robots living and working together in space

Brahms models the human-robot interaction in the field.
RIALIST is the speech interface for the astronauts and system.
Mobile Exploration System software, the host infrastructure, includes computers in crew backpacks, on vehicles and hand-held tablets.
ScienceOrganizer is a semantic data repository for the crew and remote science teams.

Haughton-Mars Project

planetary exploration technologies and strategies tested at Mars-like Haughton Crater in Canadian high Arctic environment

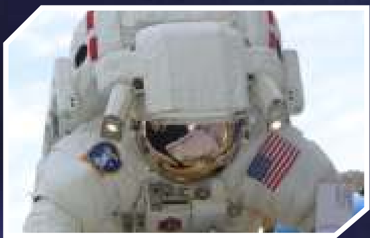
Single Cycle Instrument Placement

a suite of rover technologies developed and tested at Ames Research Center’s Marscape on its K9 rover for faster, more efficient planetary science investigation

Life in the Atacama Desert

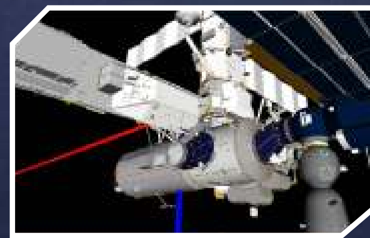
during robust operations over multiple days, rover executive recovers independently from anomalies caused by interaction with the environment and software faults

ISS Validation, Experiments



CLARISSA

advanced spoken dialogue system will read ISS procedures to astronauts so the crew can keep eyes and hands on their tasks



SimStation

3D modeling and simulation tool linked to data repository shows ISS engineers and planners system trade-offs during design, construction and operation

Flight Demonstration

Intelligent Flight Control

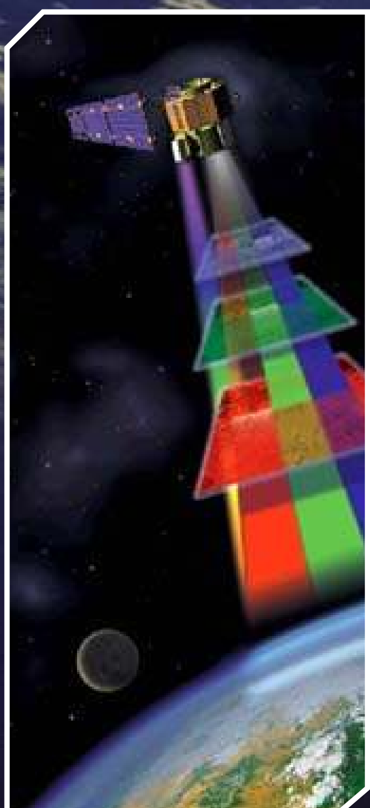
intelligent controller architectures that adapt in the midst of uncertainty or failure

Deployed

Aviation Data Integration System

FAA has made this Web-based archive that integrates weather data from more than 2,000 airports available to airlines

EO-1 Satellite



Livingstone 2

model-based diagnosis engine flies with Earth-orbiting satellite to detect failures in space system

ST5 Mission

Evolvable Systems

automated engineering design and optimization of systems scheduled for launch with NASA's ST5 mission

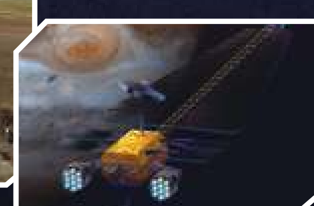
On Tour

Personal Exploration Rover

inexpensive rover fleet touring museums of the world to give visitors hands-on lessons in planetary rover exploration mission planning

Future Mission Support

technologies for the Mars Phoenix Lander, Mars Science Laboratory rover and Jupiter Icy Moons Orbiter missions



ISS

The International Space Station

The International Space Station is serving as a testbed for future exploration technology. A key goal for new technology is to increase safety and reduce costs associated with building, maintaining and conducting science on the station, as well as develop and test future mission technologies for a return to the moon and for exploration of Mars and the solar system.

Ames Research Center's Computational Sciences Division is providing tools for the ISS and is conducting research for advanced technologies in the following areas:

- human and robotic interaction
- autonomous spacecraft and robots
- crew communication networks and systems
- information and data management
- modeling, simulation and visualization
- software validation and verification
- multi-agent teaming
- vehicle health maintenance

http://ic.arc.nasa.gov/destination/iss/

Clarissa

ADVANCED SPOKEN DIALOGUE SYSTEM

NASA will deploy an advanced spoken dialogue system called CLARISSA in the fall of 2004 for tests on the ISS. CLARISSA is designed to save astronauts time and make them more efficient by reading procedures to them.

ISS astronauts execute thousands of complex procedures onboard the ISS to maintain life support systems, check out space suits, conduct science experiments and perform medical exams, among their many tasks. Today, when carrying out these procedures, an astronaut reads from paper procedures, or a PDF viewer on a laptop computer, which requires the astronaut to shift attention from the task to scroll PDF pages.

CLARISSA can play the role of a procedure reader, enabling astronauts to be more efficient with their hands and eyes and to give full attention on the task. In addition to reading procedure steps, CLARISSA can answer simple questions, display pictures, read ahead, take voice notes and navigate through a procedure to other steps when commanded to do so.

An unpiloted Russian cargo craft is scheduled to deliver CLARISSA. This winter, ISS astronauts will use CLARISSA onboard the ISS to assist them with procedures for making sure the station's water is safe.

The astronauts will use CLARISSA part of the time to read and navigate the ISS's three potable water analysis procedures, two-hour plus procedures for collecting the station's potable water for chemical and microbial analysis. Then researchers will compare how the astronauts performed using the tool versus how they were able to work without it.

Ames researchers say that the tool will create a safer work environment. And, because in microgravity, everything floats away if you let go of it, a speech-based system like CLARISSA would provide the astronauts with an advantage.

"We've had a lot of support from the astronauts," said CLARISSA project scientist Beth Ann Hockey. "Most of them really like this idea."

Plans call for integrating CLARISSA with the ISS International Procedure Viewer, making CLARISSA a feature with all ISS procedures.

CLARISSA's capabilities also include:
Allowing the user to correct or undo commands
Distinguishing speech intended for it from speech among other people
Giving the user spoken context-sensitive help

Reference resolution: user can say "read the last step" or "repeat the last caution" and Clarissa will calculate which step or caution was meant

In the future, similar conversational abilities could let people talk to robots in natural language. This capability will be useful for hands-free interaction with team members and robotic assistants. CLARISSA paves the way for other voice interfaces to systems, including systems on robots that will help astronauts diagnose medical conditions and monitor life support, among potential human-robot collaborations.

CLARISSA was built using Regulus, an open source system for creating domain-specific language models, developed partly at NASA Ames. Regulus language models are used with speech recognition software provided by Nuance Communications in Menlo Park, Calif.

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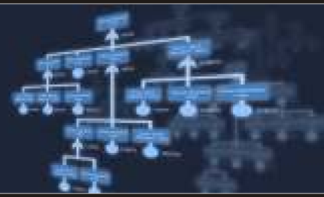
The Computational Sciences Division is developing and maturing technolo

Risk Management



Project Lead: David Maluf
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NASA's mission is inherently risky. A Risk Information Grid is being developed that will integrate the large amount of risk information associated with each mission that exists in numerous databases and in varied document types. This will integrate the agency's information grid technology, which provides seamless access to distributed information resources such as super computers, software and databases, with risk management processes. Prototypes are being developed for mishap management, program management and risk management.

CLARISSA

Project Lead: Jim Hieronymus
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NASA will deploy the advanced spoken dialogue system CLARISSA in the fall of 2004 for tests on the ISS. CLARISSA is designed to save astronauts time and make them more efficient by reading procedures to them. Today, when carrying out these procedures, an astronaut reads from paper procedures, or a PDF viewer on a laptop computer, which requires the astronaut to shift attention from the task to scroll PDF pages. CLARISSA will read procedure steps, answer simple questions, display pictures, read ahead, take voice notes and navigate through a procedure to other steps when commanded to do so.

Information Grid

Project Lead: David Maluf
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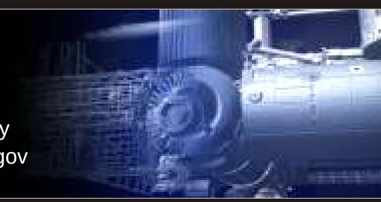
Reports, drawings, procedures, presentations, e-mail messages. Maintaining and expanding the ISS generates an enormous pool of information. To improve the operation of ISS requires rapid retrieval of precise information from its varied sources spread across multiple distributed, heterogeneous databases. Distributed Virtual Information Directory (DAVID) and Netmark technologies are part of an extensible database architecture for an Information Grid of heterogeneous and distributed information resources.

SimStation



Project Lead: Mark Shirley
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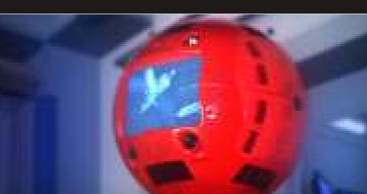
SimStation will help vehicle system engineers improve their "big picture" understanding of ISS vehicle design and operational trade-offs and then bring that understanding to a wide range of analysis tasks. The tool provides a 3D model of the ISS, a model for answering many questions about relationships between the station's parts and links to the enormous vehicle documentation repository. SimStation also includes a link to NASA's vehicle telemetry repository via the Diagnostic Data Server, also under development at Ames.

PSA



Project Lead: Greg Dorais
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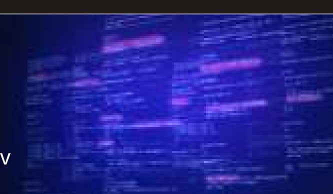
The Personal Satellite Assistant is a free-flying spacecraft robot prototype designed to help astronauts inside the ISS perform day-to-day tasks and to serve as a testbed for developing and refining future technologies for human-robotic interaction. The PSA will communicate with computers on the station and alert astronauts and mission control if a problem arises. The autonomy software being developed for the PSA will be adjustable. The robot is being designed to work onboard the station but the software will be useable on robots that work outside spacecraft, in other planetary atmospheres and on planetary surfaces like Mars.

ISET



Project Lead: Larry Markosian
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International Space Station software contains one million lines of code that are difficult to debug using traditional testing methods because the possible outcomes during execution are usually infinite. A team conducted several case studies with Marshall Space Flight Center on the application of a commercially available automatic verification tool. The goal was to evaluate the effectiveness of advanced verification technology in detecting defects in several ISS software components. The tool, which covers all possible execution paths without executing the program, found bugs that had not been uncovered using traditional testing methods.

gies that will enable safer, more affordable and efficient space exploration

DAT

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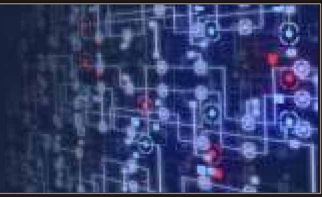

The Databus Analysis Tool (DAT) allows monitoring of the databuses, the nerve system of ISS, permitting engineers to track the functions of the Command and Data Handling system. This system is 30 computers in a three-tiered network responsible for the commanding and data acquisition of the station’s subsystems. The DAT was employed during the successful checkout of the Control Momentum Gyros, which are used for keeping the spacecraft properly oriented, in October 2000. Astronauts Bill McArthur and Leroy Chiao used the DAT to power and spin up each of the gyros on the station's Z1 truss before installation of the U.S. Lab.

ADS

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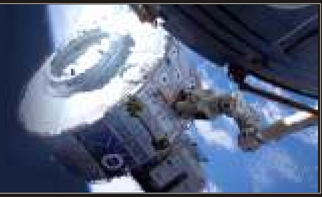

The Advanced Diagnostic System (ADS) is a testbed supporting research in developing diagnostic systems that will help astronauts and mission controllers keep the spacecraft’s critical support systems working properly. It has two components: the Diagnostic Data Server and the a set of Diagnostic Client Applications (DCAs) that are served data from the DDS. The DDS contains station telemetry, shuttle telemetry and other ISS simulation data.

DDS

Project Lead: Rick Alena
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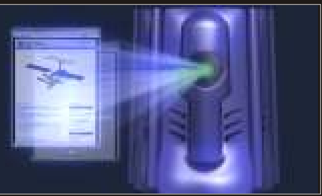

The Diagnostic Data Server (DDS) is intended to simplify and speed up acquisition of relevant station data that is needed to develop and use diagnostic tools under the Advanced Diagnostic System framework. DDS provides Web-based access to the station’s large, well-indexed repository of vehicle telemetry. It also can provide context-sensitive searches for datasets to meet a diagnostic developer’s criterion, as well as stream network data from historical archives, avionics testbeds and even from the real ISS vehicle. DDS gets the data ready for the developers and finds cases in space and ground-based tests relevant to the developer’s research.

Wireless ISS

Project Lead: Rick Alena
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The Computational Sciences Division did much of the pioneering work for on-board wireless network capability. The Wireless Network Experiment (WNE) tests in 1995 and 1996 were proofs of concept for wireless network technology in space, and as a result wireless local area networks (LANs) are now in use aboard the ISS to enable science and station operations. LANs keep the crew informed of the station’s orbit status and allow interaction with payloads and science experiments. Launched in November 1995, WNE was developed for the ISS Phase 1 Program and was a joint effort with the Russian Space Agency.

Strider

Project Lead: Peter Robinson
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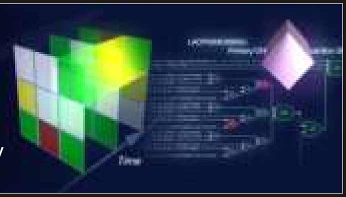

Strider is a Diagnostic Client Application focused on the Command and Data Handling (C&DH) subsystem. C&DH is made up of 30 computers and one million lines of software code in a three-tiered network responsible for the commanding and data acquisition of the subsystems. When problems occur on the C&DH, Strider will help astronauts and mission controllers find the root cause of anomalies by searching through thousands of possibilities. It will automatically map links among the ISS hardware and software models.

IVS

Project Lead: Richard Papasin
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The Intelligent Virtual Station (IVS) is a software framework that gives astronauts, trainers and flight controllers access to the NASA Johnson Space Center training facility within a virtual ISS environment. Using a keyboard and mouse or joystick with most PC computers, a user can move easily inside and outside the station to interact with its parts while accessing relevant documents. Flight controllers and trainers can generate virtual training procedures for astronauts, to help them visualize the steps required to handle a science experiment or replace a component on the station.

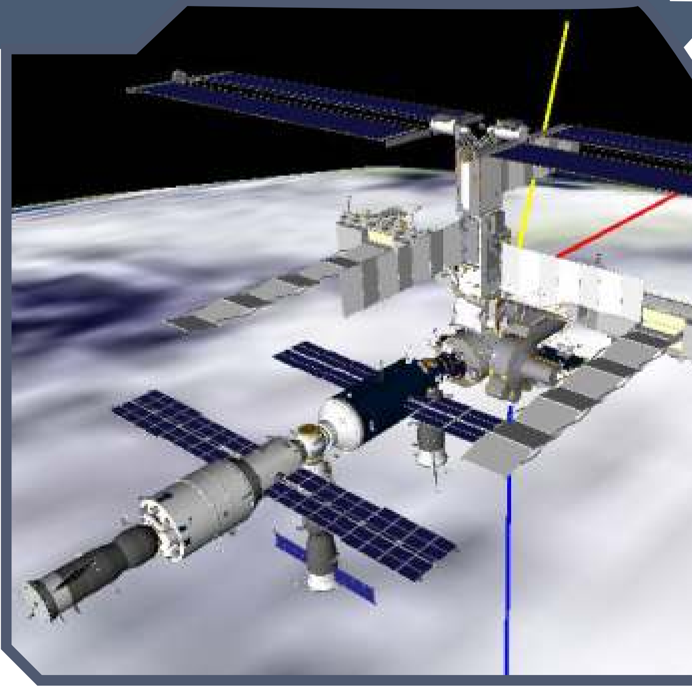
SIMSTATION

ENGINEERING DECISION SUPPORT

An engineering knowledge management tool under development at NASA Ames called SimStation is a digital model of the International Space Station (ISS) designed to help engineers make better decisions about the station's construction and operation.

"The goal is to provide a system dynamics simulation of the major behaviors of the station," says project lead Mark Shirley.

In addition to simulation, SimStation provides engineers with a 3D model of the ISS for answering questions about relationships between the station's subsystems and modules to mitigate risk and to deal with increasingly complex vehicle systems. "We want SimStation to help people develop an intuitive understanding of a very complex system."



An increasingly complex machine
The ISS is the most complex vehicle ever flown, with thousands of engineers in 16 countries contributing to the design, maintenance and assembly of its systems.

The station is being flown and constructed in stages in orbit. As such, tracking the changes is a huge challenge. For example, adding a new part might only slightly affect the station's power distribution, but effectively outdate all the documents and models describing the station's behavior.

As the ISS is assembled, the ISS program responds to unforeseen events such as budget cuts, technology and engineering innovations and insights into how the station's systems and components work together once they're online. Meanwhile, the volume of information associated with ISS grows, and the station becomes an even more complex machine.

Managing that machine
The ISS systems engineers perform about 50 trade studies a year to determine the consequences of some proposed change in a system, a vehicle configuration or mission design. These engineers need to know how the systems' parts work together to achieve the station's behavior. For example, what components are supplying power to a particular laboratory rack, or what else will fail if a particular component fails?

"These are questions for which answers are available, but it's often time consuming to find the answer," Shirley says. "We're trying to make answering basic questions about the vehicle more efficient. What if we moved this part there, for example? Engineers ask these sorts of questions all the time."

SimStation runs on a desktop or laptop. The tool is tailored to the needs of the systems engineers who perform the trade studies, giving them a virtual vehicle for a comprehensive view of a wide range of options for understanding how to build and maintain a safe, efficient ISS.

"Determining the functional impact with design changes is extremely difficult and requires access to many nonintegrated sources," says Shirley. "We're trying to build a framework to put those connections into place."

The SimStation project
Building SimStation requires integrating information from a wide variety of sources, many of which use different keys and naming conventions. To do this, a novel process of joining databases was developed by heuristically matching English language fields. This technique, called Database Reconciliation, is potentially useful for integrating other kinds of databases as well.

SimStation combines functionality from several other research efforts: the Synergistic Engineering Environment project at Langley Research Center, the Bird's Eye View project at Johnson Space Center and the Intelligent Virtual Station and Diagnostic Data Server (a tool that serves both telemetry and simulation data) projects at Ames Research Center.

Many projects modeling various aspects of the space station exist, but these projects have mostly been isolated. The SimStation project has commissioned the creation of several reusable software components for vehicle modeling from these projects and added several more of its own.

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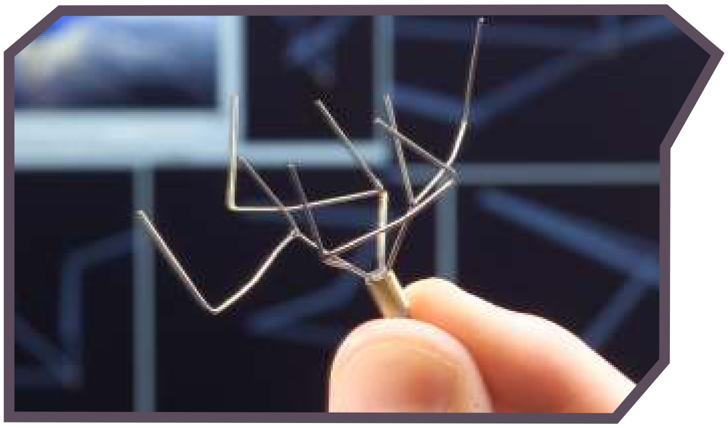
EVOLVABLE SYSTEMS



The Evolvable Systems Group's evolved antennas are being prepared for tests that will determine if they are flight qualified for the mission scheduled to orbit in the Earth's magnetosphere after 2004.

The New Millennium Program's Space Technology 5 (ST5) mission will test multiple technologies and mission concepts in Earth's orbit for future use. Each technology represents a breakthrough in performance, capability or application in a new and unique manner. Once launched with ST5, the antennas will be the first evolved hardware ever flown on a NASA mission. On ST5 the antenna will both relay satellite data to the ground and accept commands sent from Earth to the satellites.

The evolved antenna is a product of evolvable systems research, an emerging set of computer methods using algorithms that are creative and are termed invention machines because of their demonstrated ability to produce patentable inventions.

Evolvable Systems research aims to develop automated design software that will:
- design tools that dramatically increase the effectiveness of systems engineers and mission planners
- allow field-programmable gate arrays (FPGAs) to recover from radiation and temperature-induced faults
- design high-precision MEMS gyroscopes for spacecraft navigation systems
- design autonomous robotic and habitat controllers
- design and optimize large-scale structures such as launch vehicles, spacecraft, rovers and habitat modules
- assist mission planners with automatic exploration and optimization across mission planning trade-off spaces

Evolvable systems algorithms are highly adaptable, relatively fast, and can be set up to optimize cost, robustness and performance by embedding these measures directly into the multi-objective utility functions making up the algorithms.

As an example, the Evolvable Systems Group's initial design for ST5 was as good as a human-designed model and outperformed the model in critical metrics such as mass and cost. A second design was evolved in fewer than four weeks after an orbit change, proving that the techniques aid designers in adapting quickly to changing requirements.

In addition to antennas, the Evolvable Systems Group builds algorithms that design chips that rewire themselves, circuits, coevolutionary algorithms and schedules for satellite fleets. But antennas have been a focus because of their importance in NASA missions and because antennas are difficult to design. In the future, evolutionary algorithms may become a common tool for designers.

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PER

PERSONAL EXPLORATION ROVER

The Personal Exploration Rover (PER) is a miniature six-wheeled robot that gives the public hands-on lessons in robotics and planetary exploration.

The rover is among a fleet of 40 NASA-funded PERs that can be found in museums exhibits across the United States and overseas, including the Smithsonian Institution in Washington, D.C.; the Exploratorium in San Francisco; the National Air and Space Museum in Augusta, Ga; and the Jane’s Farnborough International Air Show in England.

Each rover is 1.2 feet tall, weighs 10 pounds and can move 1.6 inches per second across a Mars yard. In a three-minute demonstration, the visitor plays “the mission planner,” selecting a rock target from among those that the rover’s panoramic imager displays on a monitor, and deciding how far the rover needs to turn and drive to reach the rock. The tiny vehicle moves across the red landscape to the target. Each rover’s mobility system is similar to the Mars Exploration Rover Mission's Spirit and Opportunity.

PER teaches kids that robot autonomy for planetary exploration is much more complicated than a remote control car or plane that can be controlled in real time with a joystick. A 20-minute communication delay between Earth and Mars means the mission staff drives the rover blindly, and might not see a hazardous obstacle until the rover stops to return data from its next location.

“Our goal is to excite and inspire kids about science and technology and educate people about the role of rovers and rover autonomy in doing space science,” said Illah Nourbakhsh, an associate professor of robotics on leave from Carnegie Mellon’s School of Computer Science. “We want people to understand why it's important for the rovers to be smart.”

The PER project was first developed by researchers at Carnegie Mellon with support from NASA and Intel Corp., to teach and encourage the development of low-cost robotic devices for use in education and at home.

“With the Personal Exploration Rover, students can learn how robots interact with the world and see for themselves how the future might look as we have more and more robots helping us in our everyday life,” said G. Scott Hubbard, director of NASA Ames Research Center.

Nourbakhsh led the PER project while at Carnegie. Each rover costs about $7,000.

The PER project is funded as part of a four-year grant from NASA to develop educational robots. It is supported through the NASA Ames Intelligent Systems Program and Intel. The PERs are powered by Intel Xscale technology using the Intel PXA255 processors, which provide high system performance and low power consumption. The rovers run the Linux operating system and are programmed in Java.

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Intelligent Flight Control

Adapts in the midst of failures

An Intelligent Flight Control (IFC) system designed to improve an aircraft's ability to sustain severe damage will be flown on a modified F-15 aircraft at NASA Dryden Flight Research Center in 2005.

NASA Ames and Dryden, Boeing Phantom Works and the Institute for Scientific Research Inc., have teamed up to develop and test IFC, which uses neural networks to directly adapt to aircraft damage and control surface malfunctions. The system targets one of the largest classes of fatal aircraft crashes, a category known as "loss of control in flight."

NASA Ames sponsored IFC research at Georgia Tech several years ago, and with Dryden and Boeing later modified the system to develop "Gen-II" (second-generation IFC) based on a series of flight simulation studies. Ames is responsible primarily for neural network development and integration. These neural networks will reside on an advanced flight control computer called the Airborne Research Test System (ARTS) II that was developed by the Institute for Software Research.

The latest in this series of architectures, Gen-III, was developed at Ames and evaluated in a piloted flight simulation study in 2003. Discussions are under way to conduct Gen-III flight tests roughly one year from the Gen-II flight tests.

Intelligent control architectures such as IFC rely on nature-inspired, mathematically sound problem-solving tools to adaptively arrive at control solutions in the midst of uncertainties and failures.

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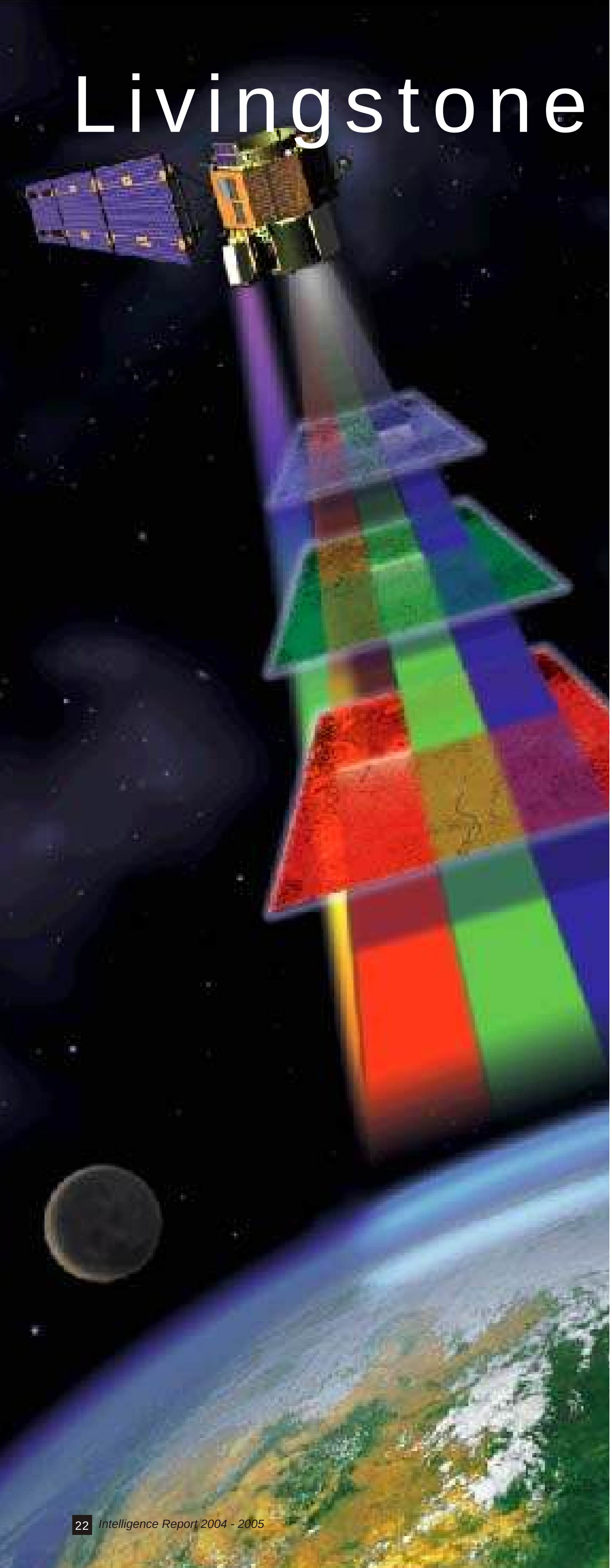
Livingstone



Remote Diagnosis of Spacecraft System Failures

Software that can automatically detect degradations or failures in space systems before complex problems become critical could significantly reduce mission operations costs, boost mission efficiency and could one day save a rover, a spacecraft or even a human life.

In a test of autonomous diagnostics this summer, NASA computer scientists at Ames will deploy the Livingstone Version 2 (L2) software, which will automatically identify and diagnose a number of simulated failures occurring in the science instruments of an Earth observing satellite.

Diagnosis in Space

The New Millennium Mission's first Earth Observing (EO1) satellite was launched in 2000 as a platform for testing new technologies and strategies for improving missions while reducing cost and development time. NASA's Goddard Space Flight Center manages the satellite.

Livingstone will run at times when NASA JPL's autonomy software, the Autonomous Sciencecraft Experiment (ASE), is in control of the spacecraft.

In this first flight, L2 will watch for things to go wrong with the spacecraft while the autonomy software executes the satellite's imaging process, and will automatically diagnose any failures and send the diagnosis to Goddard. In follow-up flights, the autonomy software will use the information to determine the best way to continue and achieve its science goals despite failures.

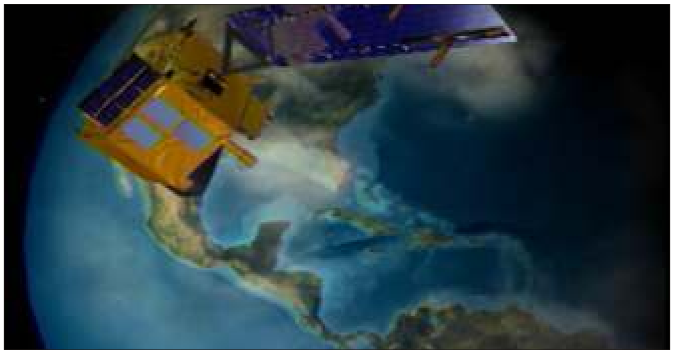
"Cutting-edge space technologies are growing in complexity and sophistication, as we embark on more ambitious space ventures," said Sandra Hayden, principal investigator and project manager for the Livingstone on EO-1 experiment.

"That's why it is critical to make sure these systems behave as their designers intended, and to diagnose accurately when things go wrong. This gives us a chance to recover from errors, protect our investments in space, and continue on to achieve our mission goals. Model-based diagnosis is a means to that end."

The Demonstration

L2 on EO1 is Ames' first demonstration in space since 1999, when the first version of Livingstone flew on the Deep Space One spacecraft with the Remote Agent Experiment, an autonomy demonstration named one of the 10 greatest achievements in artificial intelligence.

Livingstone uses a model of the system to predict its behavior. If actual behavior diverges from the model's predictions, a diagnosis is made to isolate the cause of the discrepancy to a specific failure. The first version of Livingstone could give mission operators only a single



candidate for an error. L2 provides several hypotheses of what went wrong. L2 updates a diagnosis based on the histories of the sensor data and the commands that have been sent to the spacecraft. L2 continually monitors a spacecraft's state and history, providing the most accurate, up-to-date diagnosis in real time.

Supporting Exploration Systems

A tool like L2 would have been helpful this spring when Mars Exploration Rover (MER) Mission staff realized that rover Opportunity had spent the previous day spinning its wheels on the slippery soil of a crater slope.

During a blind drive, the rover had taken a right turn, which should have been made outside the crater, while still inside the crater. A worst-case scenario could have been a toppled-over rover, and an untimely end to the $400 million mission.

During the MER mission, more than 200 mission staff members worked around the clock to oversee the direction and safety of two MER rovers. For future, affordable long-duration rover missions, that number will have to be cut drastically.

Before sending humans to Mars, where Earth-based crews cannot monitor what is happening in real time, better automatic diagnostic tools for spacecraft and robots are needed. When people start traveling deeper into space, automatic diagnostic tools can tell crew and controllers about a potential problem in sufficient time to make repairs.

"In a future long-duration (at least two years) human mission to Mars, things will fail. Frequent and extensive spacecraft maintenance operations or overhauls will not be an option, so we need to get smarter about recognizing degradations or failures early on and mitigating their impact on the success of the mission," says Serdar Uckun, ISHM technology lead for Ames Research Center's Exploration Systems Office.

Research Overview

Researchers at Ames built models of the EO1 spacecraft, its instruments, its cameras and one of its processors. L2's model-based diagnosis approach is more technically advanced than traditional approaches. The Livingstone reasoner is given a model of the system over which it is to watch. This separation between the reasoner and the object of the diagnosis means that with less effort, Livingstone can be applied to diagnose new systems. The diagnostic reasoner doesn't need to change; only a new model has to be developed for the system to be diagnosed.

Many systems have the same parts, such as valves, switches and sensors, so a model can be built more quickly by reusing these common parts. In this fast-paced experiment, the development of the models and the integration of L2 with the autonomy software onboard EO-1 has all been done within the last year. L2 can also use the same model for simulation and diagnosis. In the future, models might be developed that can be used both for planning and diagnosis.

Another planned extension is for L2 to address software failures. Current mission protocol for preventing failures is manual software testing. However, bugs inevitably slip through. Meanwhile, software code is growing in size as vehicles become more complex, introducing more likelihood for errors, creating a prime opportunity for L2 to add value.

Livingstone has proven valuable as a research tool in academia and as a diagnostic application at several NASA centers. The tool has been used in several NASA technology demonstrations. Livingstone developed a strong following in the aerospace industry through NASA's Space Launch Initiative, an effort to define, develop and test technologies for a reusable launch vehicle.

The continued research and development of tools like L2 will make future NASA missions safer, more affordable, and more effective.

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