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Wednesday, May 18, 2011

AN INTRODUCTION TO RAPID

The Robot Application Programming Interface Delegate (RAPID) is a set of software data structures and routines that simplify the process of communicating between multiple diverse robots and their command and control systems. RAPID is not intended to be an all-encompassing API for robot communication, but rather it's a compatibility layer that permits tools and robotic assets to exchange data and information and allows operators to communicate with heterogeneous robots in a uniform way. RAPID is a compatibility layer that delegates information between robots that speak different languages.

The RAPID specification includes definitions and APIs for messages and services that support supervisory telerobotics operations over near-Earth time delay. RAPID is not a middleware specification, although safety and time-delay capabilities do imply requirements on implementing middleware systems. As currently implemented, the RAPID system can be considered a software reference implementation for remote operations.

Motivation and Need[1]

NASA has expressed its interest in collaborating with international partners for exploration beyond low Earth orbit. This has been both from the agency[2] in meetings with other space faring nations and with direction from the White House[3] in the 2010 release of the US Space Policy. During 2009 and 2010 NASA engaged ESA, JAXA, CSA and other agencies in the development of a Global Point of Departure for lunar exploration. The International Architecture Working Group (IAWG) found a wide range of international partnership opportunities for lunar exploration[4]. The IAWG's Robotics Functional team identified several ideas[5], including robotic precursors, human-robotic assistants, crew mobility, long duration robotic servicing, and payload offloading of both US and international landers. This mix of robotics engineers from ESA, JASA, NASA and CSA also developed a large scale robot relocation strategy called the "International Robotics Convoy" that could move assets between crew landing sites and cover more ground than a campaign of isolated sorties. Engaging international teammates shifted the discussion from who would provide the single robot, to which combination of robots is best, and built momentum for precursors and more sustainable ideas like a relocating convoy.

Development and Field Test

Development of the RAPID system was initiated by the Human-Robotic Systems Project within NASA's Exploration Systems Mission Directorate's Exploration Technology Development and Demonstration

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[1] Robert O. Ambrose (personal communication, November 23, 2010)

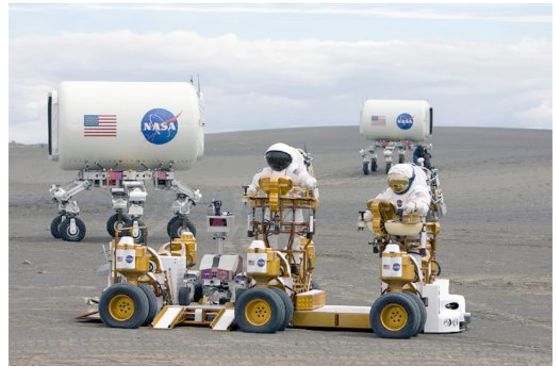
[2] http://www.nasa.gov/home/hqnews/2010/jun/10-155_ISECG_Meeting.html

[3] http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

[4] http://www.nasa.gov/pdf/315840main_International_Partnerships_and_Interface_Standards_for_Exploration_final_Laurini.pdf

[5] http://www.lpi.usra.edu/meetings/leag2010/presentations/TuePM/troutman.pdf

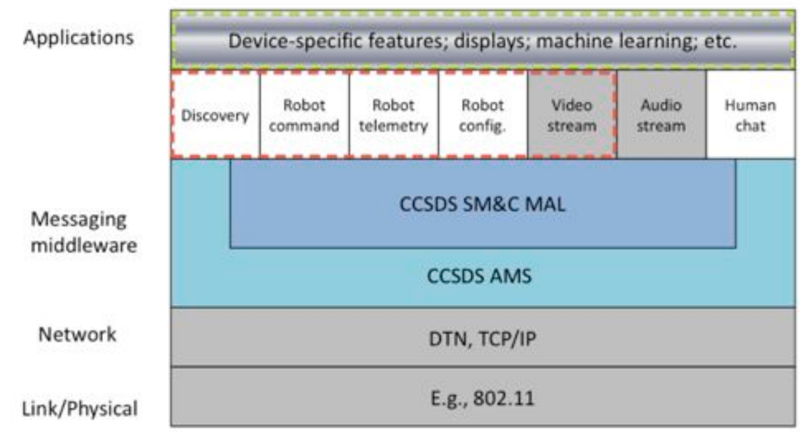
Program's (ETDDP) Foundational Element. RAPID development receives additional support from the Human Exploration Telerobotics Project within ETDDP's Demonstration Element.



A precursor to the current RAPID system was field-tested in FY2007, and the current RAPID system has been field-tested yearly since FY2008. The RAPID team participates in the Desert Research and Technology Studies (D-RATS) field tests (pictured), generally held in late summer in the high desert of Arizona.

The RAPID ecosystem now includes participation from the Jet Propulsion Laboratory, Johnson Space Center, Ames Research Center, Glenn Research Center, and Langley Research Center. We hope to expand NASA participation to the Kennedy Space Center in FY2012. RAPID robots include JPL's ATHLETE, JSC's SEV, Centaur 2, and Robonaut 2, ARC's K10, LaRC's LSMS Crane, GRC's EVAIS and ESA/ESTEC's EXARM Exoskeleton.

International Participation and Collaboration



The RAPID system began to attract international interest at the Advanced ISS Telerobotics and Communication Technical Interchange Meeting at ESTEC (Noordwijk, The Netherlands, 5-6 October 2010). During that meeting, high-level representatives of NASA, ESA and CSA recognized the need to identify common interfaces to support the development and demonstration of the advanced technologies needed for future crewed space exploration. Within NASA there are numerous planned near-term demonstrations of critical capabilities to enable human deep-space exploration. The demonstrations will use a wide range of platforms and venues, including analog field tests, the ISS, Flagship flight experiments, and robotic precursor missions. There are many opportunities for international collaboration in this bold new exploration program, and NASA is seeking partners. The RAPID system has been identified as one technology with the capability of enabling the collaboration necessary to achieve these shared mission goals.

The RAPID team hopes to contribute to the CCSDS Telerobotics Working Group process by sharing their collaborative supervisory field robotics experience in discovery, robot command, telemetry, and configuration control (outlined in red).[6] The RAPID ecosystem includes a broad range of mission planning, execution and monitoring tools not described in this document. These tools occupy the area outlined in green, but are not part of the RAPID system. Organizations that participate in the RAPID project are free to adapt their own tools to use the RAPID message and service system; they may also choose to share their

[6] Scott Burleigh, "A Strawman Gap Analysis for US-TRSIG," 14 April 2011.

tools with other members of the RAPID ecosystem if such sharing serves their interests. There is no requirement that RAPID members share their RAPID-adapted proprietary intellectual property.

RAPID has been released under the NASA Open Source Agreement, is currently hosted as the Robot API Delegate project at SourceForge, and is mirrored at rapid.nasa.gov.

RAPID Messages and Services

RAPID defines the commands that can be sent to RAPID-enabled agents and categorizes closely related actions, such as image acquisition, with a command group. The following command groups are defined:

Admin	Provides high-level test functions and control parameters.
ImageSensor	Used to capture images from Agent-mounted cameras.
Miscellaneous	Provides access to Agent-specific commands not specified in other command groups.
Mobility	Controls the motion of navigable rovers over a surface.
Queue	Controls task execution within the Sequencer.
AccessControl	Governs transfer of control of agents between operators.

RAPID defines common telemetry messages for robot position and configuration as well as imaging and non-imaging sensor data sets and system state.

Position	Provides Agent position and pose.
Joint	Provides Agent joint frames and positions.
Point Cloud	Provides location and data format details for point cloud-type science data sets.
Image Sensor	Provides image sensor state and image data.
Frame Store	Provides coordinate frame tree with initial values.
Access Control	Provides current controller and control requests and command queue status.

RAPID also defines common services that greatly increase the ability of RAPID agents to collaborate on common telerobotic tasks.

Sequencer	Enables time-delayed teleoperation of robotic agents through a synchronous command queue.

Frame Store	Provides location awareness between robots. Implemented as a classic tree of coordinate frames and tree-walking routines for calculating coordinate transforms. The frame store is updated from robot telemetry.
Asynchronous File Transfer	Provides a robust file delivery mechanism between RAPID agents.

The RAPID Team

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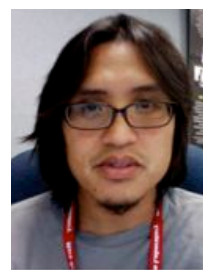
David Mittman is the Task Manager for Human System Interaction within the Exploration Systems Mission Directorate's Human Robotic Systems Project, and oversees the implementation of new operations technologies for JPL's ATHLETE robot. David also leads the development of a set of common inter-center advanced operations technologies for JSC's Space Exploration Vehicle, ARC's K10 rovers, LaRC's Lunar Surface Manipulation System crane and JPL's ATHLETE rover.



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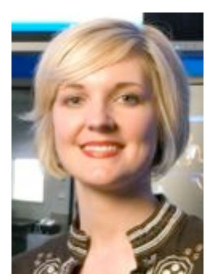
R. Jay Torres is a staff member of the Planning Software Systems Group at the Jet Propulsion Laboratory in Pasadena, CA. Jay is the Cognizant Engineer and Lead Developer for the RAPID inter-center operations command and telemetry protocol. Jay is the also lead developer for the Maestro Planning application for the Mars Exploration Rover (MER) Project.



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Kimberly Hambuchen is a robotics engineer in the Software, Robotics and Simulation division at NASA Johnson Space Center. She received a B.E. in biomedical engineering and electrical and computer engineering (1997) and an M.S. (1999) and Ph.D. (2004) in electrical engineering, all from Vanderbilt University. She currently specializes in developing novel methods for remote supervision of space robots over intermediate time delays, and has participated in NASA analog field tests to determine the validity of these methods using multiple NASA robots including the JSC Space Exploration Vehicle and Centaur platforms, the JPL ATHLETE cargo-handling vehicle and the ARC K10 rover. Her other research interests include human-robot interaction and robot perception. She is a former NASA Graduate Student Research Program fellow and previously held a postdoctoral position at NASA through the National Research Council.

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Dr. Burridge received a dual B.A. in Mathematics and Engineering Sciences (Electrical) from Yale University, and an M.S. and Ph.D. in Computer Science and Engineering from the University of Michigan. He has spent most of the time since 1997 as a Senior Scientist at TRACLabs, providing support to NASA JSC's Intelligent Systems Branch and Robotic Technologies Branch. The focus of his research has been on Human-Robot Interaction, specifically in adjustable autonomy and intelligent robot supervision. He was Principal Investigator for the EVA Robotic Assistant (ERA) project, where he was responsible for development and field-testing of a small autonomous mobile robot designed to assist astronauts on a planetary surface. In 2005, he was JSC lead for Robonaut in the Peer-to-Peer project, which sought to improve human-robot teamwork. In 2007, he was the JSC lead for an inter-center project investigating remote command and control of several different robots across time delay. This team developed the Predictive Interactive Graphical Interface (PIGI), for which Dr. Burridge produced several of the key software components. PIGI helps compensate for time delay between a remote operator and a robot. He has worked with Robonaut, Centaur, and SEV, and is a founding member of the RAPID group, which is developing an inter-center standard for robot communication.

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Mark B. Allan is a Senior Software Engineer with the Intelligent Robotics Group at NASA Ames Research Center. Mark specializes in data visualization and has worked in the areas of ground control systems for remote exploration, novel human-computer interfaces, massively parallel data flow architectures, and flight simulators. Current topics of interest include the use of virtual worlds to effectively explore remote worlds, application of technology to enhance individual and team effectiveness, and architectures that enable efficient human-robotic coordination.

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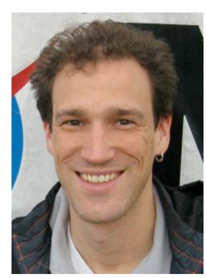

Hans Utz is a Senior Systems Scientist for the Carnegie Mellon University working with the Intelligent Robotics Group (IRG) at NASA Ames Research Center. He is the software lead for IRG's rover platforms. His work is concerned with the development of advanced software architectures for autonomous mobile robotics. Before joining NASA ARC, he was a PhD student at the Department of Neuroinformatics, University of Ulm, Germany. He designed the robotics middleware Miro and coached the Ulm Sparrows, a project on "autonomous mobile robotics in highly dynamic environments," which is probably better known as robot soccer. He has a doctorate in Computer Science from the University of Ulm, Germany.