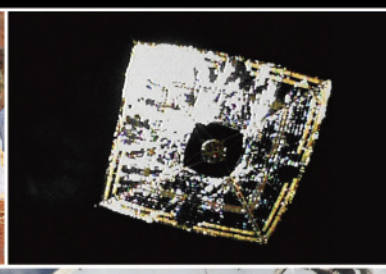
i-SAIRAS 2010

The International Symposium on Artificial Intelligence, Robotics and Automation in Space
August 29 - September 1, 2010
Sapporo Convention Center, Sapporo, Japan



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JAXA
Japan Aerospace Exploration Agency

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Message from the General Chair

Welcome !

I am very pleased to welcome all participants of i-SAIRAS2010.

i-SAIRAS2010 (international Symposium on Artificial Intelligence, Robotics and Automation in Space) will be held August 29th to September 2nd, 2010 in Sapporo, Japan. (Aug. 29th is only for registration and reception Sept. 2nd is for the technical tour. Paper presentations will be Aug. 30th to Sept. 1st.) i-SAIRAS2010 is also the 10th in the series of international symposiums.

i-SAIRAS began in 1990 in the city of Kobe, Japan to provide an opportunity for collaboration, for the diverse researchers and users of the space borne AI, robotic and automation technologies. The strength of i-SAIRAS comes from these symposium participants.

There were several revolutionary space missions after the 1st i-SAIRAS. JAXA (including the former NASDA) developed and launched the ETS-VII robotic satellite and the Hayabusa spacecraft conducted an autonomous landing on a small body and returned to Earth. NASA/JPL explored Martian surface by robotic rovers. Construction of the International Space Station is in progress with participation of a lot of space agencies. I believe that i-SAIRAS has contributed to realize these missions.

I hope every participant of i-SAIRAS2010 enjoys the symposium and the city of Sapporo.

Finally, I would like to thank friends who organized i-SAIRAS2010.
I would like also to express thanks from the i-SAIRAS2010 Organizing Committee to JAXA which provided financial support for the organization of i-SAIRAS2010.

Mitsushige Oda; Prof. PhD.
Aerospace Research and Development Directorate
Japan Aerospace Exploration Agency
Professor, Tokyo Institute of Technology

< Note >

i-SAIRAS2010 was proposed by the i-SAIRAS International Executive Committee which is made up of representatives from supporting space agencies, and is organized by the i-SAIRAS2010 Organizing Committee with financial support from JAXA in cooperation with Japan Society of Aeronautical and Space Sciences (JSASS), Japan Society of Mechanical Engineers (JSME), Japan Society of Artificial Intelligence (JSAI), Robotics Society of Japan (RSJ), and Society of Instrument and Control Engineers (SICE). Selection of the papers to be presented at i-SAIRAS2010 was conducted by the i-SAIRAS2010 Program Committee.

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Highlights of i-SAIRAS 2010

Following the previous meetings held in Kobe (Japan 1990), Toulouse (France 1992), Pasadena (USA 1994), Tokyo (Japan 1997), Noordwijk (The Netherlands 1999), Montreal (Canada 2001), Nara (Japan 2003), Munich (Germany 2005), and Hollywood (USA, 2008), i-SAIRAS 2010 is the 10th in this series of international symposia. The meeting is devoted to the technology of Artificial Intelligence (AI), Automation and Robotics (A&R) and its application in space. The symposium will take place in Sapporo, Japan from August 29 to September 2, 2010. A special theme of the 10th i-SAIRAS is "Human-Robotic Systems and Operations for Exploration." The main topics to be covered by the symposium are:

Artificial intelligence for space systems:

- Spacecraft autonomy: Onboard software for mission planning and execution, resource management, fault protection, science data analysis, guidance, navigation and control, smart sensors, testing and validation, architectures;
- Mission operations automation: Decision support tools (for mission planning and scheduling, anomaly detection and fault analysis), innovative operations concepts, data visualization, secure commanding and networking;
- Design tools and optimization methods, electronic documentation;
- Artificial intelligence methods (automated planning and scheduling, agents, model-based reasoning, machine learning and data mining).

Robotics and automation for space systems:

- Application scenarios (e.g. space base assembly and servicing, external and internal payload tending, satellite inspection and servicing, planetary and cometary exploration, ground processing), programmatic and utilization aspects;
- Robotics technologies for A&R systems, support equipment, ground segments, mobility, manipulation, end effectors and tools, sensing and robot vision, control, robot-friendly payload design, walking and climbing robots, test and operations;
- Technology for (non-robotic) space laboratory automation, payload control systems, data communications, imaging, user interfaces and telepresence/telescience.

Human-Robotic Systems and Operations for Exploration:

- Human-robotic teaming concepts (task allocation, safety, transfer of control authority), crew autonomy vs. ground-based control vs. vehicle/system autonomy, human-computer interaction, state-based commanding, monitoring and control.

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Mitsushige Oda, Ph.D.
Space Robotics Research Group, Aerospace Research and Development Directorate, Japan Aerospace Exploration Agency (JAXA)

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Manager, Mission Software, Computing, and Networking Program Office, Jet Propulsion Laboratory (JPL)

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Program Executive for Solar System Exploration, Science Missions Directorate, NASA Headquarters (NASA)

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Head, Technologies Requirement and Planning, Space Technologies, Canadian Space Agency (CSA)

Bernd Sommer, Dipi. Phys., MSE
Head Automation and Robotics for Space Applications, German Aerospace Center

Gianfranco Visentin
Head, Automation and Robotics Section, European Space Agency (ESA), European Space Research and Technology Centre (ESTEC)

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Masahiro Nohmi (Kagawa University)
Keiki Takadama (The University of Electro-Communications)
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Takehisa Yairi (The University of Tokyo)
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Hiroshi Ueno
Atsushi Ueta
Gianfranco Visentin
Lui Wang
Dave Wettergreen
Brian Wilcox
Thomas Wolf
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Yasuyoshi Yokokohji

General Information on Sapporo

Sapporo, the fifth largest city (with a population of approximately 2 million people) of Japan, is the capital of Hokkaido which is the northernmost of the four main islands of Japan. Historically, Sapporo is best known as the first Asian city to host the Winter Olympic games in 1972. Surrounded by beautiful nature, Hokkaido has attracted a number of tourists from other parts of Japan and nearby Asian countries. The late summer season around the symposium dates is the best time to enjoy a variety of marine and land products, such as fresh sea food and vegetables. A short trip around Sapporo during the stay will offer great cultural and natural experiences, which you will not have encountered in the other cities in Japan. Please don't forget that Sapporo is also famous for a variety of sweets which are ideal as gifts for your family and colleagues.

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Symposium Site

Sapporo Convention Center (SCC)

ADDRESS: 1-1-1 Higashi-Sapporo 6-jo, Shiroishi-ku, Sapporo, Japan 003-0006

TEL: +81-11-817-1010

FAX: +81-11-820-4300

Office hours 9:00-18:00

URL: http://www.sora-scc.jp/eng/index.html

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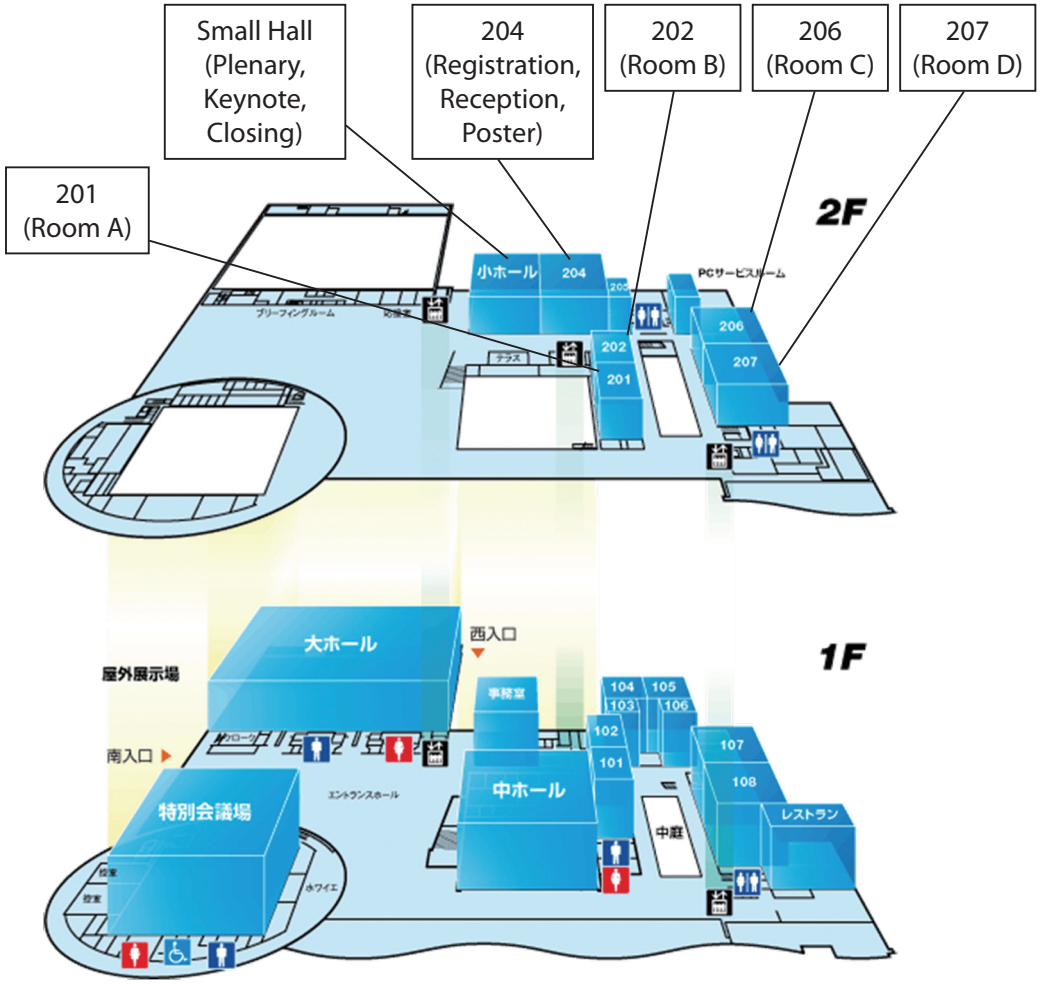
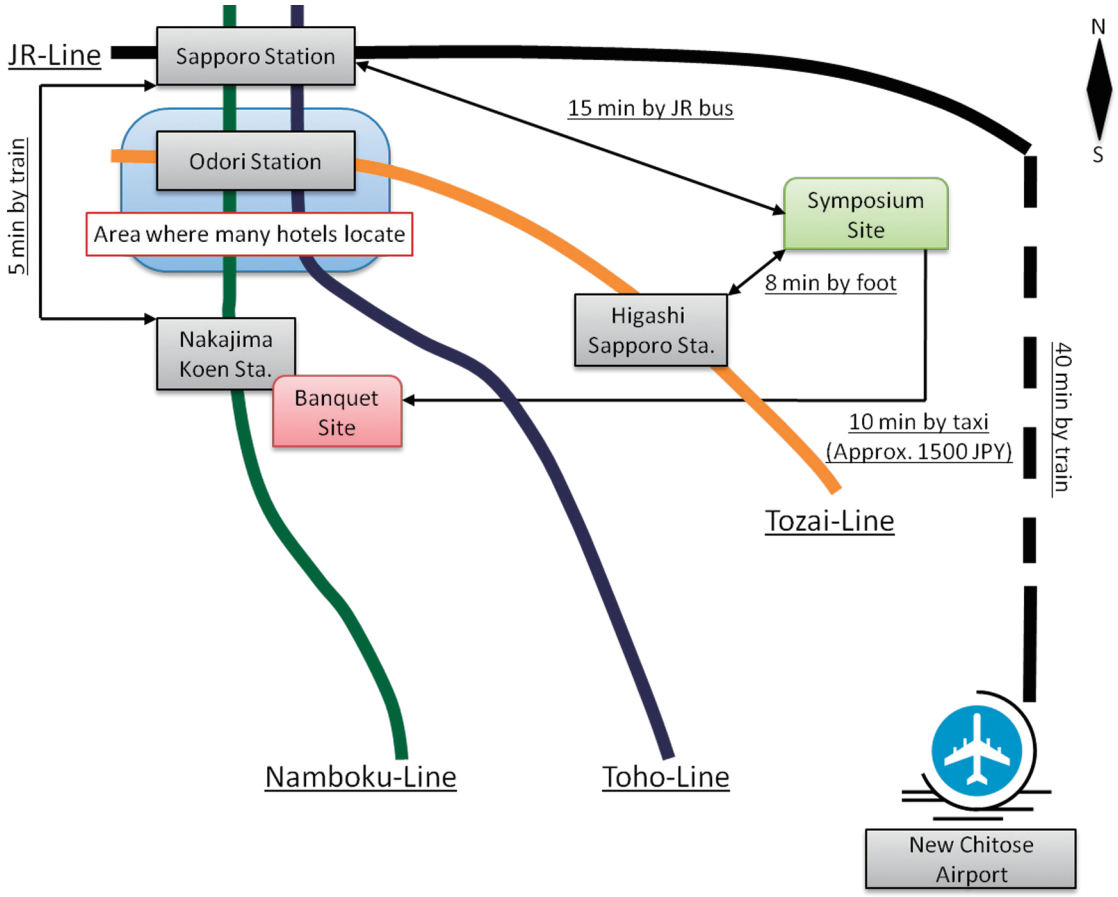
Floor Map of Symposium Site

All technical sessions including plenary, keynotes, and posters are held on the second floor of the Sapporo Convention Center (SCC).



Travel Information

Following figure simply shows where the symposium site, the banquet site, and the near stations are in Sapporo.



Recommended access to the symposium site from the hotels area:

- Take metro on the Namboku-line or Toho-Line.
- Change metro to Tozai-Line at the Odori Kohen.
- Get-off at the Higashi Sapporo (East Sapporo).
- Walk 8 minutes to the symposium site.

In addition, there is a JR Bus service from JR Sapporo Station to the symposium site (approx. 17 minutes).

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Social Events

Welcome Reception

A welcome reception will be held on Sunday, August 29th from 4pm to 6pm at Room 204 of the symposium site (SCC). Drinks and light meal will be provided. All registered participants are invited.

Banquet

The banquet will be held in the evening of Tuesday, August 31st at Sapporo Park Hotel starting from 6:30pm. Detailed information about the transportation from the symposium site will be announced. The full registration includes a banquet ticket.

Technical Tour

Technical tour (or excursion) will be organized on Thursday, September 2nd, one day after all the schedule of the symposium. Participation costs 4,000 JPY which includes fee of transportation, lunch box, participation of the following events at Uematsu Electric Co., Ltd..

- Short Lecture of Hybrid Rocket (CAMUI Rocket)
- Miniature Rocket Assembly and Flight Experience
- Factory Tour including Observation of Rocket Combustion Test

Schedule of Tour :

Symposium Site (9:15) → Uematsu Electric Co., Ltd. (11:00-15:00) → Sapporo Beer Museum or Sapporo Station (17:00)

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Program at a Glance

Sunday August 29th	Monday August 30th	Tuesday August 31st	Wednesday September 1st	Thursday September 2nd
	09:15- Registration	09:15-09:50 Keynote Talk	09:15-10:30 W1:Technical Sessions	09:15-18:00 Technical Tour
	10:00-10:10 Welcome	Break		
	10:10-12:40 Plenary Talks	10:10-12:40 T1:Technical Sessions	10:35-11:50 W2:Technical Sessions	
			Break	
			12:05-12:40 Keynote Talk	
	Lunch	Lunch	Lunch	
15:00-18:00 Registration	13:50-15:30 M1:Technical Sessions	14:00-15:40 T2:Technical Sessions	14:00-16:05 W3:Technical Sessions	
	Break			
16:00-18:00 Welcome Reception	15:50-17:55 M2:Technical Sessions	Break		
		1600-17:30 Poster Session	Break	
			16:25-17:00 Closing Session	
		18:30-21:00 Banquet		

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i-SAIRAS2010 Technical Program Monday, August 30, 2010

	Room A (201)	Room B (202)	Room C (206)	Room D (207)
09:15-	Registration			
10:00-10:10 10:10-12:40	**Welcome Address** (Small Hall) **Plenary Session** (Small Hall)			
12:40-13:50	Lunch			
13:50-15:30	**Session: M1A** Planning and Scheduling	**Session: M1B** Docking and Capture	**Session: M1C** Advanced Robotic Landing	**Session: M1D** Lunar or Planetary Exploration
20 min	Break			
15:50-17:55	**Session: M2A** Spacecraft Controller	**Session: M2B** New Conceptual Robots	**Session: M2C** Visual Odometry and Navigation	**Session: M2D** Astronaut Support System

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i-SAIRAS2010 Technical Program Tuesday, August 31, 2010

	Room A (201)	Room B (202)	Room C (206)
09:15-09:50	**Keynote Talk** (Small Hall) "The Phoenix Mars Lander Surface Mission", Barry Goldstein, California Institute of Technology, JPL		
20 min	Break		
10:10-12:40	**Session: T1A** Autonomy	**Session: T1B** On-Orbit Service and Tele-Robotics	**Session: T1C** Rover Design and Mobility
12:40-14:00	Lunch		
14:00-15:40	**Session: T2A** Rover Systems and Software	**Session: T2B** Operation and Support Tool	**Session: T2C** Robotic Exploration
20 min	Break		
16:00-17:30	**Poster Session** (Room 204)		
18:30-	Banquet		

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i-SAIRAS2010 Technical Program Wednesday, September 1, 2010

	Room A (201)	Room B (202)	Room C (206)
09:15-10:30	**Session: W1A** Science Autonomy	**Session: W1B** Multi-Robot Exploration	**Session: W1C** Rover Modeling and Simulation
10:35-11:50	**Session: W2A** Drilling System	**Session: W2B** Decision Support	**Session: W2C** Walking Rover
15 min	Break		
12:05-12:40	**Keynote Talk** (Small Hall) "Hayabusa's Challenge - World's First Round-Trip Flight to An Extra-Terrestrial Object, Itokawa" Jun'ichiro Kawaguchi, JAXA		
12:45-14:00	Lunch		
14:00-16:05	**Session: W3A** Robotic Systems	**Session: W3B** ISS and Human Operations	**Session: W3C** Rover Field Test
20 min	Break		
16:25-17:00	Closing (Small Hall)		

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MONDAY, AUGUST 30, 2010

Plenary Session (10:10-12:40, Small Hall)

Japan's Space Policy and the Space Robotics

Mitsushige Oda, JAXA, Japan

Opportunities for Automation and Robotics in the evolving NASA Human Space Flight Strategy

Chris Culbert, NASA/Johnson Space Center, USA

AI and Robotics at ESA in 2010

Gianfranco Visentin, ESA, The Netherlands

Canadian Space Agency Activities in Space Exploration

Jean-Claude Piedbœuf, CSA, Canada

Automation and Robotics in the German Space Program – From Orbital Applications to the Exploration of our Solar System

Bernd Sommer, DLR, Germany

Session M1A : Planning and Scheduling (13:50-15:30, Room 201)

Optimising Ground Stations Scheduling with a Genetic Algorithm

Junzi Sun, Ed Chester, Marcel Quintana (CTAE), Spain

The DSN Scheduling Engine (DSE): Automated Scheduling of Activities for the NASA Deep Space Network

Mark D. Johnston, Daniel Tran (JPL), USA

Multi-Objective Scheduling for Space Science Missions

Mark D. Johnston (JPL), Mark E. Giuliano (STSCI), USA

Technology Infusion via Certification-based Analysis

Russell Knight (JPL), USA

Session M1B : Docking and Capture (13:50-15:30, Room 202)

On-Orbit Testing of Target-less TriDAR 3D Rendezvous and Docking Sensor

Srephane Ruel, Tim Luu, Andrew Berube (Neptec Design Group Ltd.), Canada

EPOS – A Robotics-Based Hardware-in-the-Loop Simulator for Simulating Satellite RvD Operations

T. Boge, T. Wimmer, O. Ma, M. Zebenay (DLR/GSOC), Germany

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Motion Planning for the On-orbit Grasping of a Non-cooperative Target Satellite with Collision Avoidance

Roberto Lampariello (DLR), Germany

Robust Uncalibrated Visual Servoing for Autonomous On-Orbit-Servicing

Azad Shademan, Amir Farahmand, Martin Jagersand (University of Alberta), Canada

Session M1C : Advanced Robotic Landing (13:50-15:30, Room 206)

3D Imaging LIDAR for Autonomous Planetary Landing

Florian M. Kolb (Jena-Optronik), Ingo Ahrns (EADS Astrium), Bettina Möbius (Jena-Optronik), Germany

A New Strategy to Land Precisely on the Northern Plains of Mars

Yang Cheng, Andres Huertas (JPL), USA

Vision Technologies for Small Body Proximity Operations

Adnan Ansar, Yang Cheng (JPL), USA

SURF-Based SLAM Scheme using Octree Occupancy Grid for Autonomous Landing on Asteroids

Cedric Cocaud, Takashi Kubota (The Univerdity of Tokyo), Japan

Session M1D : Lunar or Planetary Exploration (13:50-15:30, Room 207)

Coordinating Multiple Spacecraft in Joint Science Campaigns

Tara Estlin, Steve Chien, Rebecca Castano, Joshua Doubleday, Daniel Gaines, Robert C. Anderson, Charles de Granville, Russell Knight, Gregg Rabideau, Benyang Tang (JPL), USA

A Plan for Lunar Exploration by using Robots

Shin-Ichiro Nishida, Sachiko Wakabayashi(JAXA), Japan

MoonNEXT Rover - Design of a Mobile Payload Option to Explore the Lunar South Pole

Elie Allouis, Lester Waugh, Simon Barraclough (EADS Astrium), Marco Scharringhausen, Andreas Gibbesch (DLR), UK

CSA Exploration Core 2009 Phase 0 Studies: An Overview

Eric Martin, Jean-Claude Piedboeuf (CSA), Canada

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Session M2A : Spacecraft Controller (15:50-17:55, Room 201)

HIROSCO – A High-Level Robotic Spacecraft Controller

Martin Stelzer, Bernhard Brunner, Klaus Landzettel, Bernhard-Michael Steinmetz, Jörg Vogel, Gerd Hirzinger (DLR), Germany

Reducing Code Complexity in Hybrid Autonomous Control Systems

Louise A. Dennis, Michael Fisher (Univ. of Liverpool), Nicholas Lincoln (Univ. of Southampton), Alexei Lisitsa (Univ. of Liverpool), Sandor M. Veres (Univ. of Southampton), UK

Controller Synthesis for Autonomous Systems: a Constraint-Based Approach

Cédric Pralet, Michel Lemaître, Gérard Verfaillie, Guillaume Infantes (ONERA), France

Evolving ANNs for Spacecraft Rendezvous and Docking

Jürgen Leitner, Christos Ampatzis, Dario Izzo (ACT), The Netherlands

An AO*-like Algorithm Implementation for Active Diagnosis

Elodie Chanthery, Yannick Pencolé, Nicolas Bussac (CNRS ; LAAS), France

Session M2B : New Conceptual Robots (15:50-17:55, Room 202)

Improving Recovery Capability of Multiple Robots in Different Scale Structure Assembly

Masayuki Otani, Kiyohiko Hattori, Hiroyuki Sato, Keiki Takadama (The University of Electro-Communications), Japan

DEOS – The German's Robotics Approach to Secure and De-Orbit Malfunctioned Satellites from Low Earth Orbits

D. Reintsema (DLR), Germany

Possibilities of Module Type Robot for Space Application

Shinichi Kimura, Yoshihiro Ozawa, Meguru Yamauchi, Jun Tsukahara, Masato Terakura (Tokyo University of Science), Japan

Spatial Locomotion of Tether Based Robot

Mitsuhiro Yamazumi (TITECH), Mitsushige Oda, Naoyuki Miura (JAXA), Taihei Ueno (Mecha Metier), Japan

A Novel High-Performance Ergonomic Exoskeleton for Space Robotic Telepresence

André Schiele, Hans-Peter Seiberth, Patrick Klär(ESA), Gerd Hirzinger (DLR), The Netherlands

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Session M2C : Visual Odometry and Navigation (15:50-17:30, Room 206)

Vision-Based Motion Estimation for the Exomars Rover

F. Souvannavong, C. Lemaréchal (Magellium), L. Rastel, M. Maurette (CNES), France

Mars Visual Simulation for ExoMars Navigation Algorithm Validation

Mark McCrum, Steve Parkes, Iain Martin, Martin Dunstan (Space Technology Centre, University of Dundee), UK

A Study on Planetary Visual Odometry Optimization: Time Constraints and Reliability

Enrica Zereik, Davide Ducco, Fabio Frassinelli, Giuseppe Casalino (DIST, University of Genoa), Italy

Comparative Analysis of Localisation and Mapping Techniques for Planetary Rovers

Karin Shala, Yang Gao (Surrey Space Centre), UK

Path Set Relaxation for Mobile Robot Navigation

Philipp Krüsi (ETHZ), Mihail Pivtoraiko, Alonzo Kelly (CMU), Thomas M. Howard (JPL), Switzerland

Session M2D : Astronaut Support System (15:50-17:55, Room 207)

REX-J, Robot Experiment on the ISS/JEM to Demonstrate the Astrobot's Locomotion Capability

Mitsushige Oda, Masahiro Yoshii, Hiroki Kato, Atsushi Ueta (JAX), Satoshi Suzuki (AES), Yusuke Hagiwara, Taihei Ueno (TITECH), Japan

EVA Crew Assistant Supporting Astronauts in Space Missions: Autonomy and Cooperation

Enrica Zereik (DIST, University of Genoa) , Andrea Sorbara, Andrea Merlo (Thales Alenia Space), Giuseppe Casalino (DIST, University of Genoa), Frederic Didot (ESA/ESTEC), Italy

Human-Human Inspired Task and Object Definition for Astronaut-Robot Cooperation

Seppo Heikkilä, Aarne Halme (Aalto University), André Schiele (ESA), Finland

Integrated Autonomous Navigation in a Large Planetary Exploration and Service rover

A.Medina, L.Mollinedo, F.Gandia (GMV), C.Pradalier (ETHZ), G.Paar (JR), E.Pensavalle (TASI), F.Didot, P.Schoonejans (ESA), Spain

Prototype Development of an Operator Situational Awareness and Navigation Aid for Manned Planetary Vehicles

Chris Langley, Manny Nimelman, Raja Mukherji (MDA), Régent L'Archeveque (CSA), P. Milgram (Univ. of Toronto),Canada

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TUESDAY, AUGUST 31, 2010

Keynote Talk (9:15-9:50, Small Hall)

The Phoenix Mars Lander Surface Mission

Barry Goldstein, California Institute of Technology, JPL, USA

Session T1A : Autonomy (10:10-12:40, Room 201)

Increasing the Science Return of the EO-1 Mission: A Case Study of the R5 Automated Planning Upgrade

Steve Chien, Daniel Tran, Gregg Rabideau, Steve Schaffer (JPL), Daniel Mandl, Stuart Frye (GSFC), USA

Onboard Processing for Low-latency Science for the HyspIRI Mission

Steve Chien, David Mclaren, Gregg Rabideau, Dorothy Silverman (JPL), Daniel Mandl (GSFC), USA

Benefits from Innovative Tools for Diagnostic and Planning in Mission Operations

Alessandro Donati, et al. (ESA), The Netherlands

Robustness to Bit Inversion in Registers and Acceleration of Program Evolution in On-Board Computer

Tomohiro Harada, Masayuki Otani, Yoshihiro Ichikawa, Kiyohiko Hattori, Hiroyuki Sato, Keiki Takadama (The University of Electro-Communications), Japan

Onboard Clustering of Aerial Data for Selective Data Return

David S. Hayden, Steve Chien, David R. R. Thompson, Rebecca Castano (JPL), USA

A Multi-agent Space, In-situ Volcano Sensorweb

Steve Chien, Daniel Tran, Joshua Doubleday, Ashley Davies, Sharon Keda, Frank Webb, Gregg Rabideau (JPL), Daniel Mandl, Stuart Frye (GSFC), Wenzhan Song, Behrooz Shirazi (Washington State Univ.), Richard Lahusen (United States Geological Survey), USA

Session T1B : On-Orbit Service and Tele-Robotics (10:10-12:40, Room 202)

Release Guidance Analysis using Charged Formation Flying for On-Orbit Servicing

Paul Iliffe, Saburo Matunaga (TITECH), Japan

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Autonomous Control of Operative Constrains during Real-Time Teleoperation of Space Robots

Markus Pietras, Florian Rems, Ulrich Walter (Technische Universitaet Muenchen), Germany

Experimental Head-Up Display for Space Telerobotics

Markus Wilde, Jan-Philipp Hamacher, Ulrich Walter (Technical University Munich, Institute of Astronautics), Germany

Predictive Display from Computer Vision Models

Martin Jagersand, Adam Rachmielowski, David. Lovi, Neil Birkbeck, Alexjandro Hernandez-Herdocia, Azad Shademan, Dana Cobzas, Keith Yerex (University of Alberta), Canada

Development of Improved Morphable Beam Device with Rotation Based Shaper

Shintaro Mizunuma, Nobuhiko Kisa, Saburo Matunaga (TITECH), Japan

Deformation of Tensegrity Structure Using Tendon Actuators

Yusuke Hagiwara (TITECH), Mitsushige Oda (JAXA), Japan

Session T1C : Rover Design and Mobility (10:10-12:40, Room 206)

End-to-end Design of a Robotic System for Collecting and Transferring Samples on Mars

Elie Allouis, Tony Jorden, Nildeep Patel (EADS Astrium), Samuel Senese (SELEX Galileo), Rudolf Sporri (RUAG), Konstantinos Kapellos (Trasys), Reto Wiesendanger (EPFL), Gianfranco Visentin (ESA), UK

Control for Space Robotic Manipulator with Passively Switching Free Joint to Drive Joint

Masatsugu Otsuki, Takashi Kubota (JAXA), Japan

Conceptual Rover Design by an Integrated Optimization Process

Aravind Seeni, Bernd Schäfer, Gerd Hirzinger (DLR), Germany

Modeling and Analysis on Exploration Rover with Screw Drive Mechanism over Loose Soil

Kenji Nagaoka (Grad. Univ. Advanced Studies), Takashi Kubota (JAXA), Japan

Assessment of Tractive Performances of Planetary Rovers with Flexible Wheels Operating in Loosely Packed Soils

J.P. Pruiksma, J.A.M. Teunissen, G.A.M. Kruse (Deltares), M.F.P. van Winnendael (ESA), The Netherlands

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Travelling Performance Evaluation for Planetary Rovers on Weak Soil

Masataku Sutoh, Junya Yusa, Keiji Nagatani, Kazuya Yoshida (Tohoku Univ.), Japan

Session T2A : Rover Systems and Software (14:00-15:40, Room 201)

RTILE – Adaptive Rover Navigation based on Online Terrain Learning.

Ambroise Krebs, Cédric Pradalier, Roland Siegwart (ETHZ), Switzerland

Communication Scheduling and Plans Revision for Planetary Rovers

I. Musso, R. Micalizio, E. Scala, G. Nuzzolo, G. Martucci, P. Rosazza Prin, E. Pigozzi (Advanced Logistics Technology Engineering Center), Italy

Hybrid Architecture Agent for Planetary Surface Exploration

Pietro Francesconi, Michele Lavagna (Politecnico di Ingegneria Aerospaziale), Italy

"Rock Solid" Software: A Verifiable and Correct-by-Construction Controller for Rover and Spacecraft Functional Levels

Saddek Bensalem (Verimag/CNRS), Lavindra de Silva (LAAS/CNRS), Matthieu Gallien (Verimag/CNRS), Félix Ingrand (LAAS/CNRS), Reogjie Yan(Verimag/CNRS), France

Session T2B : Operation and Support Tool (14:00-15:40, Room 202)

Development and Realtime Monitor of JEM Robotics Operation Ground Observatory (ROGO)

Yoshiyuki Kitajima, Hiroaki Hattori (Mitsubishi Space Software Co.,Ltd), Hiroshi Ueno, Shinobu Doi (JAXA), Japan

High Speed Lunar Navigation for Crewed and Remotely Piloted Vehicles

Liam Pedersen, M. Allan, Vinh To, Hans Utz (NASA ARC/CMU), Wociech Wojcikiewicz (Humbold Univ.), Christophe Chautem(ETH), USA

Initial Operation of the Small Fine Arm of JEMRMS

Hiroshi Endo, Shinobu Doi, Hiroshi Ueno (JAXA),Japan

Pursuing Interactivity of Mission Planning Supports - A Retrospective View

Amedeo Cesta and Gabriella Cortellessa (ISTC-CNR), Italy

Session T2C : Robotic Exploration (14:00-15:40, Room 206)

An Overview of Canadian Space Robotics Activities

Erick Dupuis, Yves Gonthier, Jean-Claude Piedboeuf (CSA), Canada

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Test-bed Rovers for Planetary Surface Exploration

Takashi Kubota, Masatsugu Otsuki, Toshiharu Shimada (JAXA), Yoji.Kuroda (Meiji Univ.), Yasuharu Kunii (Chuo Univ.), Japan

FootSpring: A Compliance Model for the ATHLETE Family of Robots

Dawn Wheeler (NASA/AMES), Daniel Chavez-Clemente (Stanford Univ.), Vytas SunSpiral (CMU, NASA/AMES), USA

A Canadian Breadboard Rover for Planetary Exploration

Ryan McCoubrey, Justin Allport, Manickam Umasuthan, Layi Oshinowo (MDA), Canada

Poster Session (16:00-17:30, Room 204)

(P01) **Orbital Experiment Report of Pico-Satellite KUKAI**

Masahiro Nohmi, Kagawa University, Japan

(P02) **Stable Path Tracking with JEMRMS Through Vibration Suppression Algorithmic Singularities Using Momentum Conservation**

Naoyuki Hara, Yoshikazu Kanamiya (D. N. Nenchev), Daisuke Sato, Tokyo City University, Japan

(P03) **A Modular and Flexible Bimanipulation System for Space-Analogue Experiments**

Alejandro Hernandez Herdocia, Azad Shademan, Martin Jägersand, University of Alberta, Canada

(P04) **A Ground-Based Operation System for EVA Support Robot Experiments**

Atsushi Ueta, Mitsushige Oda, JAXA, Japan

(P05) **Economic Approach for Active Space Debris Removal Services**

Joerg Kreisel (Astrium Satellites GmbH), J.Kreisel (Joerg Kreisel Int. Consultants), Germany

(P06) **Satellite Network Architectures against Emerging Space Threats**

Frédéric Cristini, Catherine Tessier, Éric Bensana, ONERA-DCSD, France

(P07) **A Data Abstraction Architecture for Mission Operations**

Scott Bell, David Kortenkamp (TRACLabs Inc), Jack Zaientz (Solar Technologies Inc.), USA

(P08) **Towards Operator Monitoring via Brain Reading - An EEG-based Approach for Space Applications**

Elsa Andrea Kirchner, Hendrik Wöhrle, Constantin Bergatt, Su Kyoung Kim (RIC, DFKI), Jan Hendrik Metzen (Univ. of Bremen), Frank Kirchner (DFKI GmbH), Germany

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(P09) **Advanced Testbed and Simulation Environment for Planetary Exploration and Mobility Investigations**
Bernhard Rebele, Armin Wedler, Maximilian Apfelbeck, Heiko Hirschmüller, Sebastian Kuss, Andreas Gibbesch, Bernd Schäfer, G. Hirzinger, DLR, Germany

(P10) **Autonomous D-H Parameter Determination for a Damaged Manipulator Using Stereo Cameras**
Richard Fallows, Dave Barnes, Steve Pugh (Aberystwyth University), UK

(P11) **Divergent Stereo Visual Odometry for a Hopping Rover on an Asteroid Surface**
Edmond Wai Yan SO (The Graduate University for Advanced Studies), Tetsuo Yoshimitsu, Takashi Kubota (ISAS/JAXA), Japan

(P12) **Lightweight Arm Operations for Planetary Sample Return**
Laurence Tyler, Dave Barnes (Aberystwyth Univ.), Paul McMahon (EADS Astrium), UK

(P13) **Discussion of a Self-Localization and Navigation Unit for Mobile Robots in Extraterrestrial Environments**
Juergen Rossmann, Christian Schlette, Markus Emde, B.Sondermann (RWTH, Aachen Univ.), Germany

(P14) **Path Planning for Distributed Rover Science**
Andrew Klesh (JAXA/JSPEC), Japan

(P15) **Preliminary Study on Optical Utilization of Spacecraft Shadow Images**
Naoko Ogawa (JAXA/JSPEC), Japan

(P16) **Robust and Opportunistic Autonomous Science for a Potential Titan Aerobot**
Daniel Gaines, Tara Estlin, Steve Schaer, Alberto Elfes (JPL), USA

(P17) **Verification of Intelligent Systems Throughout the Software Life Cycle**
L.Hartman (CSA), Canada

(P18) **Knowledge based Science Target Identification System (KSTIS)**
Stephen Pugh, Dave Barnes (Aberystwyth Univ.), Derek Pullan (Univ. of Leicester), Laurence Tyler (Aberystwyth Univ.), UK

(P19) **Robotic Deployment System For Space Exploration**
D.Sanz, M.Garzon, A.Barrientos (UPM-CSIC), Spain

(P20) **On Cooperation In A Multi Robot Society For Space Exploration**
David Leal Martínez (Aalto Univ. School of Science and Technology), Jürgen Leitner (ESA), The Netherlands

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(P21) **Classifying Autonomy for Mobile Space Exploration Robots**
Sylvain Joyeux, Jakob Schwendner (DFKI), Germany

(P22) **New Approach to Touch Sensing Technique Based on Measurement of Current Generated by Electrostatic Induction**
Koichi Kurita, Kochi National College of Technology, Japan

(P23) **Multiobjective Optimization Genetic Algorithms for Domestic Airline Crew Pairing Problems**
Tung-Kuan Liu, Chiu-Hung Chen (Institute of Engineering Science and Technology), Jyh-Horng Chou, Wen-Hsien Ho, Shinn-Horng Chen (National Kaohsiung Univ. of Applied Sciences), Taiwan, R.O.C.

(P24) **Manipulator Control for Physical Astronaut-Robot Interaction**
Melak Zebenay (DLR), Seppo Heikkilä (Aalto Univ.), Germany

(P25) **Centre for Space Human Robotics of IIT@Polito: a New Italian Initiative**
Simona Ferraris,Franco Fossati (TAS-I), E.P.Ambrosio, D.Manfredi, L.Lombardi, M.Quaglio, S.Bianco (Center for Space Human Robotics), Pieluigi Civera, Mario Calderale, Fabrizio Pirri (Politecnico di Torino), Italy

(P26) **Multi-body Techniques to Model Rover Motion on Soft Terrains**
Pietro Francesconi, Giuseppe Di Mauro, Riccardo Lombardi, Michèle Lavagna, Politecnico di Ingegneria Aerospaziale, Italy

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WEDNESDAY, SEPTEMBER 1, 2010

Session W1A : Science Autonomy (9:15-10:30, Room 201)

Design and Testing of the ExoMars Sample Preparation and Distribution System

Wolfgang Schulte, Tor Viscor, Markus Manhart, Peter Hofmann (Kayser-Threde GmbH), Edoardo Re (Selex Galileo), Pietro Baglioni (ESA/ESTEC), Germany

Automatic Pointing and Image Capture (APIC) for ExoMars type Mission

Stephen Pugh, Laurence Tyler, Dave Barnes (Aberystwyth University), UK

AEGIS Automated Targeting for the MER Opportunity Rover

Tara Estlin , Benjamin Bornstein, Daniel Gaines , David Thompson, Rebecca Castano , Robert C. Anderson, Charles de Granville, Michael Burl, Michele Judd, Steve Chien (JPL), USA

Session W1B : Multi-Robot Exploration (9:15-10:30, Room 202)

Towards a Modular Reconfigurable Heterogeneous Multi-Robot Lunar Exploration System

Florian Cordes (DFLI), Daniel Bindel (ZARM), Caroline Lange (DLR), Frank Kirchner (DFKI - Robotics Innovation Center), Germany

Wireless Sensor Web for Rover Planetary Exploration

A.Medina, C.Negueruela. L.Mollinedo, F.Gandia (GMV), A.Barrientos, C.Rossi, D. Sanz (UPM-CSIC), A. Puiatti, M.Mura (SUPSI), D.Puccinelli (UPM-CSIC), J.F.Dufour (ESA), Spain

Network-Guided Multi-Robot Path Planning for Resource-Constrained Planetary Rovers

Ryan Luna, Alexis Oyama, Kostas E. Bekris (UNR), USA

Session W1C : Rover Modeling and Simulation (9:15-10:30, Room 206)

Developing a Virtual Environment for Extraterrestrial Legged Robot with Focus on Lunar Crater Exploration

Yong-Ho Yoo (DFKI), Thomas Jung (RWTH Aachen Univ.), Malte Roemmermann (DFKI), Malte Rast (RWTH Aachen Univ.), Frank Kirchner (DFKI), Juergen Rossmann (RWTH Aachen Univ.), Germany

3D Virtual Platform to Validate Planetary Vehicles Design and Operations

Riccardo Lombardi, Pietro Francesconi, Mich`ele R. Lavagna (Dipartimento di Ingegneria Aerospaziale, Politecnico di Milano), Italy

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Multi-Body System and Contact Simulation within the Design Development of Planetary Surface Exploration Systems

Andreas Gibbesch, Rainer Krenn, Florian Herrmann, Bernd Schäfer, Bernhard Rebele (DLR/GAC), Elie Allouis (EADS Astrium Ltd.),Thomas Diedrich (EADS Astrium GmbH), Germany

Session W2A : Drilling System (10:35-11:50, Room 201)

The Drill and Sampling System for the ExoMars Rover

Piergiovanni Magnani, Edoardo Re, Samuel Senese, Francesco Rizzi (Selex Galileo), Alessandro Gily (Thales Alenia Space), Pietro Baglioni (ESA/ESTEC), Italy

An Earth Auger as Excavation Part for a Planetary Underground Explorer Robot Using Peristaltic Crawling

Hayato Omori, Taro Murakami, Hiroaki Nagai, Taro Nakamura (Chuo University), Takashi Kubota (JAXA), Japan

Robotic Planetary Drill Tests

B.J.Glass, S.Thompson (NASA/AMES), G.Paulsen (Honeybee Robotics), USA

Session W2B : Decision Support (10:35-11:50, Room 202)

A Tool for Scheduling THEMIS Observations

Gregg Rabideau, Steve Chien, David McLaren, Russell Knight (JPL), Sadaat Anwar, Greg Mehall, Philip Shristensen (ASU), USA

Goal Selection for Embedded Systems with Oversubscribed Resources

Gregg Rabideau, Steve Chien, David McLaren (JPL), JPL, USA

Deploying Interactive Mission Planning Tools - Experiences and Lessons Learned

Amedeo Cesta, Gabriella Cortellessa, Simone Fratini, Angelo Oddi and Giulio Bernardi (ISTC-CNR), Italy

Session W2C : Walking Rover (10:35-11:50, Room 206)

Towards an Autonomous Walking Robot for Planetary Surfaces

Martin Görner, Annett Chilian, Heiko Hirschmüller (DLR), Germany

Study on Efficient Attitude of a Multi-Legged Planetary Exploration Rover with Isotropic Leg Arrangement

Shinji Nishikori, Shinji Hokamoto (Kyushu University), Takashi Kubota (JAXA), Japan

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Effects of Wheel Synchronization for the Hybrid Leg-Wheel Robot Asguard

Ajish Babu, Sylvain Joyeux, Jakob Schwendner,Felix Grimminger, (DFKI), Germany

Keynote Talk (12:05-12:40, Small Hall)

Hayabusa's Challenge - World's First Round-Trip Flight to An Extra-Terrestrial Object, Itokawa

Jun'ichiro Kawaguchi, JAXA, Japan

Session W3A : Robotic Systems (14:00-15:15 Room 201)

High-Level Autonomy for Exploration Robotics

Mark Woods, Andy Shaw (SciSys), Ruth Aylett (Heriot-Watt University), A.Gily (Thales-Alenia Space), F.Didot (ESA/ESTEC), UK

Fault Tolerance Operation of Cooperative Manipulator

Hamid Abdi, Saeid Nahavandi, Zoran Najdovski (CISR, Deakin University), Australia

DEXARM Integration and Test Results

Andrea Rusconi, Piergiovanni Magnani (Selex Galileo), Adriano Della Pietà (Tecnomare), Pablo Campo (SENER Ingenieria Sistemas), GianantonioMagnani (Politecnico), Gianfranco Visentin (ESA), Italy

Session W3B : ISS and Human Operations (14:00-16:05, Room 202)

JEMRMS Initial Checkout and Payload Berthing

Hiroshi Ueno, Shinobu Doi, Hitoshi Morimoto (JAXA),Japan

Vibration Control of Flexible Arm for Robot Experiment on JEM

Daichi Hirano, Hiroki Nakanishi, Kazuya Yoshida (Tohoku Univ.), Taihei Ueno, Mitsushige Oda (JAXA), Takeshi Kuratomi (WEL Research), Japan

Using a Self-Confidence Measure for a System-Initiated Switch between Autonomy Modes

Thomas M. Roehr, Yuping Shi1, Frank Kirchner (DFKI Bremen), Germany

Constraint and Flight Rule Management for Space Mission Operations

Javier Barreiro, John Chachere (SGT, NASA/AMES), Jeremy Frank, Christie Bertels, A.Crocker (NASA/JSC), USA

Spatial Planning for International Space Station Crew Operations

Bradley J. Clement, Javier Barreiro (JPL), USA

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Session W3C : Rover Field Test (14:00-16:05, Room 206)

Performance Evaluation of an Heterogeneous Multi-Robot System for Lunar Crater Exploration

Sebastian Bartsch, Florian Cordes, Strfan Haase, Steffen Planthaber, Thomas M. Roehr (DFKI - Robotics Innovation Center), Germany

The Evaluation of Planetary Exploration for Rough Terrain

Takamasa Naiki (The University of Tokyo), Takashi Kubota (ISAS/JAXA), Japan

The Avatar EXPLORE Experiments: Results and Lessons Learned

Erick Dupuis,Pierre Langlois, Jean-Luc Bedwani, David Gingras, Marc Gendron, Alessio Salerno, Pierre Allard, Sébastien Gemme, Régent L'Archevêque, Tom Lamarche (CSA), canada

Field Testing of a Rover GN&C Techniques to Support a Ground-Ice Prospecting Mission to Mars

Timothy Barfoot, Paul Furgale, Braden Stenning, Patrick Carle (Univ. of Toronto), Laura Thomson, Gordon Osinski (Univ. of Western Ontario), Michael Daly (york Univ.), N.Ghafoor (MDA), Canada

Planetary Rover Visual Motion Estimation Improvement for Autonomous, Intelligent, and Robust Guidance, Navigation and Control

Joseph Nsasi Bakambu, Chris Langley, Giri Pushpanathan, W. James McLean, Raja Mukherji (MDA), Erick Dupuis (CSA), Canada

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Plenary Talks

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Japan's Space Policy and the Space Robotics

Mitsushige Oda

Japan Aerospace Exploration Agency

Tskuba-shi, Ibaraki-ken, Japan

oda.mitsushige@jaxa.jp

ABSTRACT

Japan is now reforming its space policy and its strategy. Since Japan started R&D of space science and space technologies, they were conducted by various governmental offices and agencies. In the year 2003, JAXA (Japan Aerospace Exploration Agency) was created by merging former NASDA (National Space Development Agency of Japan), ISAS (Institute of Space and Astronautical Science) and NAL (National Aerospace Lab). However JAXA and its former institutions are operation agencies whose tasks are to realize goals directed by government. It is not clear who or which organization will be responsible for Japan's space policy and strategy. Therefore, further reforming of Japan's space development and utilization policies and policies are still under discussion.

On August 2008, the Aerospace Basic Act was put in force in Japan. The Act defines a basic policy for Japan's space activities. It also demands creation of a headquarters for Japan's space policy and strategy. The HQs for Japan's space policy was established in 2008 within the cabinet office. The director of the HQs is the prime minister and all ministers are members of the HQs. However, actual operations of the HQs are managed by several advisory committees. The HQs defined the basic plan for Japan's future space development and utilization.

The basic plan puts emphasis in several areas such as (1) Ensure a Safe and Secure Life, (2) Contribute to Enhancement of Security, (3) Promote Utilization of Space for Diplomacy, (4) Promotion of R&D, (5) Foster strategic Industries for the 21st century (6) Consider environment. To meet the above basic plan, several basic strategies are defined to pursue follows programs. (a) Earth / weather observing satellites programs, (b) Positioning Satellite System, (c) for National Security, (d) Space Science Program (e) Human space activities, (f) Space Solar Power System, (g) utilization of small satellite.

Since the AI, A&R are not a mission but technology to support some mission; the roles of space AI, A&R are not necessarily stated clearly in the basic plan. However it is apparent that the space AI, A&R will play key roles in the above programs such as satellite servicing, remove of orbital debris, robotic spacecraft and exploration systems for space science programs, crew support robotic systems and building large in-orbit facility like SSPS (Space Solar Power System). Recovery of the Hayabusa' capsule on the Earth after the round trip to a small body named "ITOKAWA" showed the taxpayers that the unmanned robotic spacecraft can make wonderful results.

An advisory group that is asked to make strategy for Japan's moon explorations after the NASA was ordered by the President to halt works related with the constellations program.

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Opportunities for Automation and Robotics in the evolving NASA Human Space Flight Strategy

Chris Culbert

NASA/Johnson Space Center

Houston, TX, USA

Chris.Culbert@nasa.gov

ABSTRACT

The United States government and NASA have spent much of the last 18 months debating the future of human space flight in America. While consensus has not been reached as of this writing, we can begin to speculate on the type of opportunities that may be emerging from this discussion. The retirement of the Shuttle and the extension of the International Space Station through 2020 are very likely. The Constellation program and the plan to develop Orion, Ares, and eventual lunar bases seem less likely. There has been considerable discussion on destinations instead or in addition to the moon. The potential development and operations costs for all of these options are an important, driving concern as political elements consider how to pay for future human space flight program. Within NASA, considerable attention has been paid to understanding what kind of technologies and capabilities are needed to extend human presence beyond low earth orbit and how those technologies could be applied to different destinations.

From all of this discussion, there will emerge a variety of opportunities for using both automation technologies and robotic systems both prior to human activities and as partners with human explorers. This talk will attempt to outline some of those opportunities and discuss needed advances that will facilitate both human space exploration and terrestrial applications.

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AI and Robotics at ESA in 2010

Gianfranco Visentin

European Space Agency (ESA)

Keplerlaan 1 2200AZ Noordwijk, The Netherlands

Gianfranco.Visentin@esa.int

ABSTRACT

The paper will provide the programmatic context in which the European Space Agency (ESA) is and hence serve as orientation background, introduction and index to the several papers on ESA missions and ESA-sponsored technologies submitted to i-SAIRAS 2010. Since the last edition of i-SAIRAS the European Space Agency has undergone quite some changes in its organization, the missions that it pursues and the technology developments that it promotes.

On the subject of its organization, the interest of ESA member states to differentiate the field of space exploration in human-oriented and otherwise non-human tended missions has led to the formation of the Science and Robotics Exploration (SRE) directorate and to the Human Spaceflight (HSF) directorate.

The SRE directorate has inherited the 2 missions originally part of the AURORA program i.e. ExoMars and Mars Sample Return, and it has also embarked into a program of international cooperation with NASA, that will see shared ESA-NASA missions reaching the planet Mars every 2 years. Three of these missions (2016, 2018 and 2020) will be described into their current level of understanding and development.

The HSF directorate has instead continued the development of the ISS with its related robotic element (ERA). Finally with the signature of new agreement between ESA and RosKiosmos it appears that ERA will be flown in 2011. HSF it has also initiated a mission for technology demonstration of capabilities for Lunar landing. This mission, provisionally called MoonNext, will provide opportunities for robotics developers to implement a small rover. HSF has also made the evolution of Eurobot program into a ground demonstrator of robotics capabilities in support of crew activities in a planetary exploration context.

Research and development activities have progressed in the different branches of the ESA A&R technology tree. The paper will illustrate some achievements and new developments. AI is also present at ESA in spacecraft operation. The paper will introduce some of the recent developments on the subject and also provide visibility on how these ground-operation developments have had an impact in AI in on-board use.

The paper will finally conclude with an outlook of technology needs for future exploration missions. A recent ESA exercise on the subject has identified 8 Innovation Themes and some 20 technology assets that are not only needed for exploration, but also provide excellent opportunity for innovation at large. The paper will in particular focus on the role that AI and robotics will play in these assets. The paper will also refer to the strengths of the R&D base in Europe, derived from significant national and ESA programs and a judicious cross-fertilization with R&D in non-space domains.

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Canadian Space Agency Activities in Space Exploration

Jean-Claude Piedbœuf

Canadian Space Agency,

6767 Route de l'Aéroport, St-Hubert, Québec, Canada, J3Y 8Y9

Jean-Claude.Piedboeuf@asc-csa.gc.ca

ABSTRACT

Canada has been involved in space exploration for more than 25 years with its robotics, science and astronaut corps contributions. As part of its space plan, the Canadian Space Agency's objectives are to ensure full Utilization of the ISS, to be active in on-orbit robotics servicing, to be a partner in the scientific exploration of Mars, to participate in human exploration of the Moon, Mars and the asteroids, and to be a partner on international space astronomy missions.

To better prepare Canada for the next international era in space exploration, an Exploration Core program is underway at the Canadian Space Agency (CSA). The Exploration Core is funding prioritized technologies and systems, concept studies and terrestrial prototyping. The results of this broad effort will allow Canada to make more informed decisions concerning its contributions to, and participation in, the implementation of the Global Exploration Strategy. Concept studies cover activities such as surface mobility systems, next generation Canadarm (for on-orbit servicing), in-situ resource utilization technologies, potential Canadian contribution to the International Lunar Network, navigation, communications technologies and more. The Exploration Core Program aims at developing terrestrial prototypes of space exploration systems and deploys them in end-to-end realistic terrestrial analogue scenarios that will involve operations and science activities.

At the beginning of 2009 the Canadian Federal Government's budget included C$110M (over three-years) of stimulus funding for various space robotics terrestrial prototyping, and good progress has been made in implementing this initiative within the existing CSA's Exploration Core program

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Automation and Robotics in the German Space Program – From Orbital Applications to the Exploration of our Solar System

Bernd Sommer, Dipl. Phys. MSE

German Aerospace Center (DLR)

Königswinterer Straße 522-524, 53227 Bonn/Germany

bernd.sommer@dlr.de

ABSTRACT

In 2009 the German Federal Ministry of Economics and Technology together with DLR declared Automation and Robotics (A&R) one of the major cornerstones of the German space program.

It focuses on two main topics. One of them is the exploration of bodies in our solar system. Here the earth's moon has the highest priority. A number of current investigations will prepare Germany's contributions to further international mission to the Moon surface, to Mars, the cold planets and their moons or asteroids and comets.

The other focus of A&R for space applications will be the unmanned servicing of satellites and the robotic on-orbit assembly and maintenance of large space platforms as carriers of a variety of payloads.

The same set of basic technologies and capabilities represent the prerequisites for successful missions in both application areas. Thus the mastering of the related capabilities are high priority tasks to be tackled and accomplished within the coming five to ten years.

Standardization and Modularization are major catchwords in this context. The development of a set of basic building blocks and tools will result in high system reliability at reduced risk and costs and thus will promote and foster commercialization of space.

Supporting infrastructures consisting of transporters, robotic vehicles, storage facilities etc. will lead to dramatically increased mission flexibility. Future missions will no longer depend on the direct launch of a space asset to its operational orbit or planetary surface. On site assembly and maintenance of the systems will be become a routine.

GEO transponder parks, planetary research facilities for astronomy, industrial parks for communication, navigation or earth observation will no longer be science fiction.

Such scenario allows to get rid of the need to launch massive space crafts. Smaller and in future even reusable launchers can take over and do the job in a more economic way.

The paper presents the motivation of the German Government and DLR to put special emphasis on Space A&R. It explains the pursued goals and shows the roadmap to accomplish them. It further gives an overview over current German space projects in the area of automation and robotics. Finally it is going to be completed by elaborating on the technology transfer potential into terrestrial applications.

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Keynote Talks

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"The Phoenix Mars Lander Surface Mission"

Barry Goldstein

California Institute of Technology, Jet Propulsion Laboratory

4800 Oak Grove Drive, Pasadena, CA 91109

barry.g.goldstein@jpl.nasa.gov

ABSTRACT

The Phoenix mission was launched from the Kennedy Space Center on August 4, 2007, and successfully landed north of the Arctic Circle on Mars on May 26, 2008. Not only was Phoenix the first mission to land in the arctic region, it was the first mission to ever directly detect water on the red planet. This talk will have a brief mission overview followed by a focus on the surface mission results.

As a low cost NASA mission, Phoenix inherited residual hardware, which was originally set to launch in the 2001 Mars type-1 trajectory opportunity, however the failure of the Mars Polar Lander mission in 1999 curtailed that mission. While Phoenix inherited the hardware, it also inherited the Entry Descent and Landing architecture from that mission. Over the course of the mission development the Project team worked to uncover and retire whatever flaws they could find from the system. The results of these efforts were realized in a flawless landing in the late spring of 2008. The genesis of the mission was a water signature remotely sensed by the Odyssey orbiting spacecraft at the northern latitudes of Mars. This surprisingly strong signal provided scientists with the opportunity to look to see if there was once a habitable zone on the Red Planet. The major scientific objective of Phoenix was to look for the three constituents of biologic potential, water, energy and food (organic or other biologic building blocks).

Designed to survive 90 Martian sols in the harsh arctic environment, Phoenix provided the science community a rich set of data for 152 sols, when finally the setting sun and dust build up ended the mission. This talk provides some of the context and imagery of the highlights of the activities over that unique and exciting time.

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Hayabusa's Challenge – World's First Round-Trip Flight to An Extra-Terrestrial Object, Itokawa

Jun'ichiro Kawaguchi

Japan Aerospace Exploration Agency (JAXA)

3-1-1 Yoshinodai, Chuo Sagamihara, Kanagawa, 252-5210, Japan

Kawaguchi.Junichiro@jaxa.jp

ABSTRACT

In 2003, seven years ago, on May 9th, a small interplanetary probe, Hayabusa was launched also via a small vehicle M-V. The spacecraft, however, aimed at an enormous engineering challenge. It is the world's first sample & return attempt to / from an extra-terrestrial object, which is a near Earth asteroid, Itokawa. The flight inevitably at the same time the world's first attempt of a round-trip interplanetary cruise back home, Earth through stopping over there.

The major purposes of the Hayabusa mission consist of 1) interplanetary cruise via ion engines, 2) autonomous guidance and navigation through optical measurement, 3) sample collection under micro-gravity environment, 4) direct reentry for sample recovery and 5) the combination of low thrust propulsion with Earth gravity assist.

In 2005, Hayabusa performed five descents to the asteroid surface, and touched down the surface two times with one landing of thirty minutes long.

After that, the spacecraft suffered from fuel leak and lost its attitude and lost contact for close to two months. But the communication and the system were restored with miracle, and had commenced the ion engines cruise back home in 2007. The lives of the ion engines aboard the spacecraft reached to end in November of 2009, when the spacecraft was conceived to terminate its mission. However, another miracle of combining two engines parts to function as a single engine was devised and continued the voyage until the end of March this year.

This June, the Hayabusa successfully made a reentry as planned to the Woomera desert of Australia via several correction maneuvers. The EDL (Entry, Descent and Landing) was completely performed. Currently the capsule was moved to the curation facility of JAXA and has been under careful inspection.

This presentation will provide the outline of the mission, and will present the recovery and rescue stories especially during the return cruise.

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Digest and paper

(Monday, August 30, 2010)

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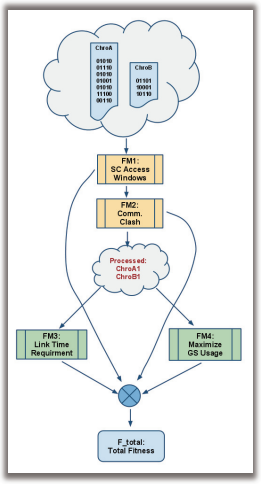
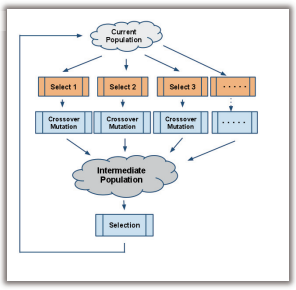
Optimising Ground Stations Scheduling with a Genetic Algorithm

Junzi Sun, Ed Chester, Marcel Quintana
Aerospace Research and Technology Centre (CTAE), Spain



Fitness Flow

- Optimise ground station scheduling belongs to combinatorial optimisation area.
- We create a mathematical model based on defined scenarios, which is solved by designated Genetic Algorithm
- Mission objectives are modularized and applied to the GA as either Serial Fitness Module or Parallel Fitness Module.
- Fitness Modules are able to be added or removed independently without affecting the rest of the system.
- A "*Over Produced and Survival Constrained Selection*" method is created to accelerate the fitness climbing.
- A decimal vector encoding is applied to the GA.



The Selection Method

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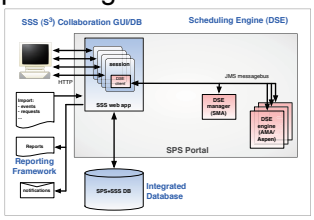
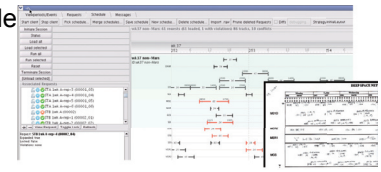
The DSN Scheduling Engine (DSE): Automated Scheduling of Activities for the NASA Deep Space Network

Mark D. Johnston* and Daniel Tran*
*Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena CA USA 91109
mark.d.johnston & daniel.tran @jpl.nasa.gov

- DSN Scheduling Engine (DSE) is the core automation component of the new DSN scheduling system, S^3 (Service Scheduling Software)
- Incorporates an expressive scheduling request specification language for users to describe tracking and other DSN requirements
- Scheduling search supports incremental schedule repair, as well as regeneration and optimization
- Robust distributed server architecture, hundreds of server instances running on multiple hosts
- DSE test client (GUI application) has been adopted for operational use since mid-2009; in deployment during 2010



DSN Scheduling System Architecture



Scheduling engine automation provides replacement for manual scheduling processes

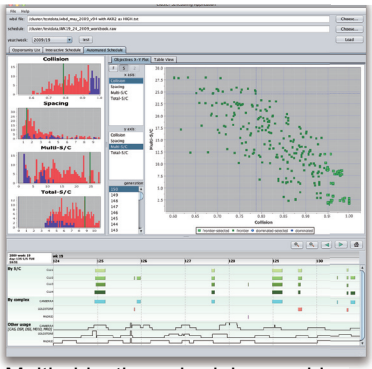
click to Paper

3

Multi-Objective Scheduling for Space Science Missions

Mark D. Johnston* and Mark Giuliano**
*Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena CA 91109, mark.d.johnston @jpl.nasa.gov
**Space Telescope Science Institute
3700 San Martin Drive, Baltimore MD 21219, giuliano @stsci.edu

- Multi-User Scheduling Environment (MUSE) provides multi-objective scheduling capabilities in a multi-participant context
- Adaptable for various missions/scheduling domains including —
  - James Webb Space Telescope
  - Cassini
  - Cluster II WBD
- Challenges include visualization of higher-dimensional objective spaces



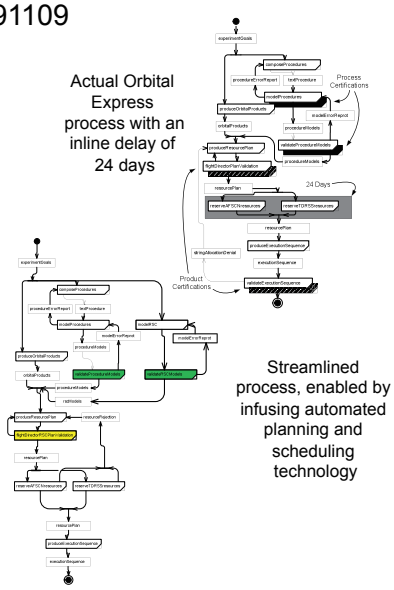
Multi-objective scheduler provides dynamic visibility into tradeoffs during scheduling and rescheduling

4

Technology Infusion via Certification-based Analysis

Russell Knight
Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, CA 91109

- Space mission architects are often challenged with knowing which investment in technology infusion will have the highest return
- Certification based analysis gives architects and technologists a means to communicate the risks and advantages of infusing technologies at various points in a process
- Various alternatives can be compared, and requirements based on supporting streamlining or automation can be derived and levied on candidate technologies.
- Examples from actual missions are given where certifying the process (as opposed to the product) resulted in significant savings



Session M1B **Docking and Capture**

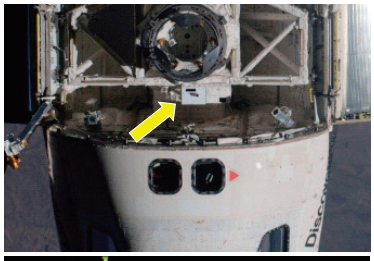
Time: 13:50-15:30
Place: Room 202

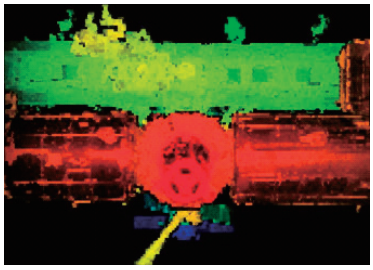
1

On-Orbit Testing of Target-less TriDAR 3D Rendezvous and Docking Sensor

Stephane Ruel, Tim Luu, Andrew Berube
Neptec Design Group, Canada

- "Target less" proximity operations sensor for rendezvous and docking
  - Uses target geometry, no cooperative targets
- Combines an active 3D sensor, thermal imager and embedded tracking software
  - Provides 6 DOF state vector out of the box in real-time
- Flight Tested on Space Shuttle during STS-128 and STS-131
  - Fully autonomous and real-time operations
  - Tracked ISS during rendezvous, docking, undocking and fly around operations



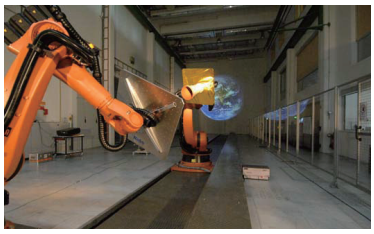


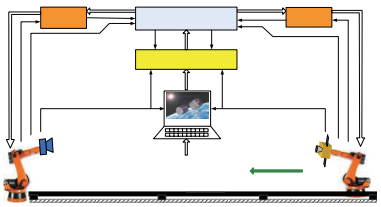
2

EPOS−A Robotics-Based Hardware-in-the-Loop Simulator for Simulating Satellite RvD Operations

T. Boge, T.Wimmer, O.Ma, M.Zebenay
*Germany Aerospace center, DLR, 82234 Wessling, Germany
e-mails: Toralf.Boge@dlr.de, Tilman.Wimmer@dlr.de, Ou.Ma@dlr.de, Melak.Zebenay@dlr.de

- Overview of the facility
- Control Architecture and requirements
- HIL contact dynamics simulation
- Control challenges and strategies
- Applications (orbit-serving missions)
  - DEOS (Deutsche Orbital Servicing missions)
  - SMART-OLEV
    (An orbital life extension vehicle)





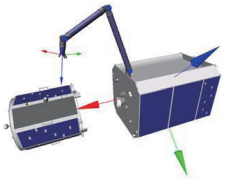
click to Paper

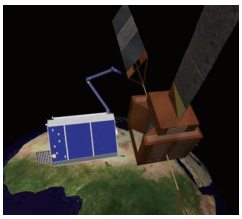
3

Motion Planning for the On-orbit Grasping of a Non-cooperative Target Satellite with Collision Avoidance

R. Lampariello
Institute of Robotics and Mechatronics, DLR, Germany

- Method based on nonlinear optimization and collision avoidance
- Motion constraints applied on robot joints and on end-effector forces
- Cost functions include robustness of planner solution and actuation energy for the approach maneuver
- Method applied on different simulation scenarios
- Impacts are carefully avoided during grasping
- Method presents an alternative to grasping with an operator in tele-presence





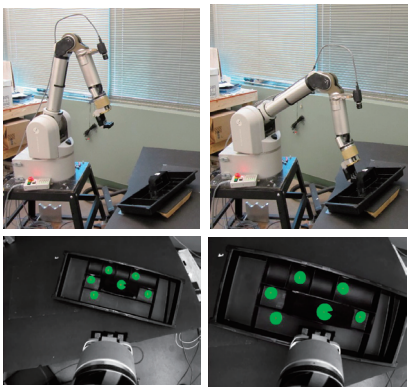
Two grasping scenarios

4

Robust Uncalibrated Visual Servoing for Autonomous On-Orbit-Servicing

Azad Shademan*, Amir Farahmand*, Martin Jagersand*
* Robotics Research Group, Department of Computing Science
University of Alberta, Edmonton, AB, CANADA

- Vision is an attractive sensor for unstructured environments, but **errors are inevitable!**
- We propose *statistically robust* vision-based control for the mating phase (capture) in OOS.
- The proposed algorithm has many advantages:
  - **Robust:** Handles outliers.
  - **Model-free (Uncalibrated):** Does not depend on calibration or target model (suitable for non-cooperative targets).
  - **Efficient:** Real-time with high accuracy.
- Simulation and laboratory experiments are provided in the presentation.
- More info: **http://www.cs.ualberta.ca/~azad**



Robot WAM arm with camera performs vision-based control (visual servoing) to grasp grapple fixture.

click to Paper

Session M1C Advanced Robotic Landing

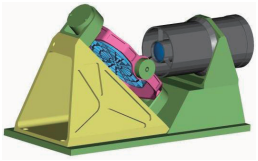
Time: 13:50-15:30
Place: Room 206

1

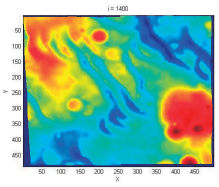
3D Imaging LIDAR for Autonomous Planetary Landing

F. M. Kolb*, I. Ahrns**, B. Möbius***
* Jena-Optronik GmbH, Jena, Germany
** EADS Astrium, Bremen, Germany
*** Jena-Optronik GmbH, Jena, Germany

- The 3D imaging LIDAR sensor concept is built on the ILT LIDAR sensor
- The sensor supports the GNC and hazard detection and avoidance subsystems by providing a 3D map of a designated area
- The requirements of a planetary landing mission have a direct influence on the LIDAR parameters
- The LIDAR parameters are strongly connected to each other
- In order to use the LIDAR data, it has to be pre-processed
- A terrestrial demonstrator mission can act as a test bed for the system



Design draft for 3D imaging LIDAR



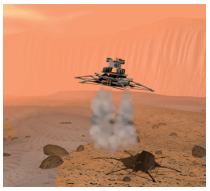
Pre-processed LIDAR data (simulation)

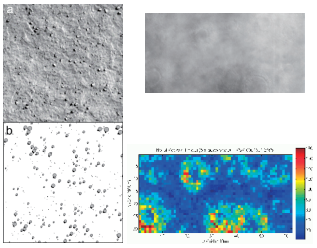
2

A New Strategy to Land Precisely on the Northern Plains of Mars

Yang Cheng*, Andres Huertas*
*Computer Vision Group, Jet Propulsion Laboratory, California Institute of Technology, USA

- A widely spread and dense rock field in the northern plains of Mars was revealed by MRO HiRISE imagery.
- A novel terrain relative navigation (TRN) algorithm, that uses abundance of rocks in northern plains for spacecraft localization during EDL, is suggested.
- A extensive feasibility study about the rock landmark TRN algorithm, including atmospheric opacity effect, illumination effect, rock landmark reliability, speed and accuracy, is given.





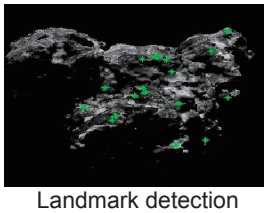
click to Paper

3

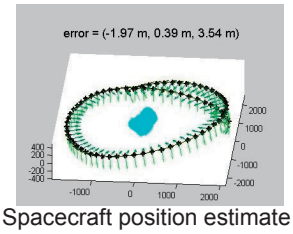
Vision Technologies for Small Body Proximity Operations

Adnan Ansar* and Yang Cheng*
*Computer Vision Group, Jet Propulsion Laboratory,
California Institute of Technology, USA

- Computer Vision technologies for image-based spacecraft localization during small body proximity operations:
  - Detect landmarks during stand-off survey phase of mission
  - Catalog landmarks and compute their target-relative 3D positions
  - Recognize landmarks during proximity operation phase of mission
  - Compute spacecraft position and attitude relative to target body using image locations of recognized landmarks and 3D positions recorded in catalog



Landmark detection



Spacecraft position estimate (black) vs. ground truth (green)

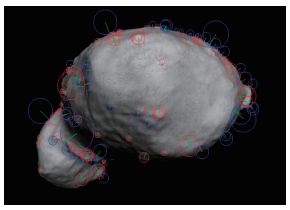
4

SURF-Based SLAM Scheme using Octree Occupancy Grid for Autonomous Landing on Asteroids

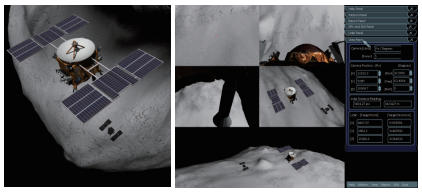
Cedric Cocaud*, Takashi Kubota**
*Department of Electrical Engineering and Information Systems,
The University of Tokyo, Japan
**Institute of Space and Astronautical Science (ISAS-JAXA), Japan

Computer Vision based SLAM (Simultaneous Localization and Mapping)

- Operates in near real-time during Approach, Descent & Landing on small celestial bodies
- Does not rely on *a priori* topographic features (e.g. craters)
- Relative pose estimation is done for every 2 successive frames taken from a navigation camera
- Uses (SURF) Speeded-Up Robust Features' invariance to lighting conditions and robustness to perspective changes for feature matching and triangulation
- Uses the SLAM optimization of landmarks position and spacecraft pose after one asteroid revolution (i.e. at loop-closure)



SURF feature extraction



Real time 3D simulator interface

click to Paper

Session M1D Lunar or Planetary Exploration

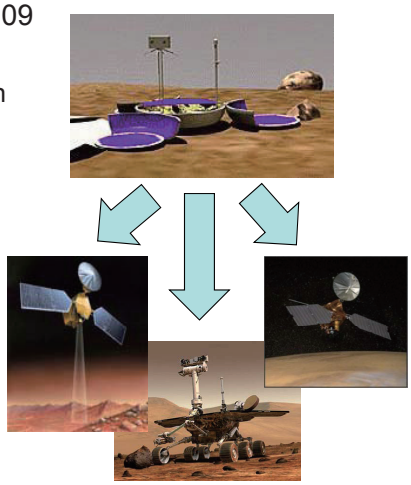
Time: 13:50-15:30
Place: Room 207

1

Coordinating Multiple Spacecraft in Joint Science Campaigns

T. Estlin, S. Chien, R. Castano, J. Doubleday, D. Gaines, R. C. Anderson, C. de Granville, R. Knight, G. Rabideau, and B. Tang
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

- Autonomous coordination of multiple spacecraft in characterizing dynamic science event
- Science events are autonomous detected and characterized
- Coordinated spacecraft can consists of multiple orbiters, landers, rover or other *in-situ* vehicles
- Technology includes techniques for onboard data analysis and automated planning and execution
- Two demonstration scenarios were used to test technology with hardware in JPL Mars Yard
- Examples of events that could be characterized from Mars include dust-devils, dark slope streaks, seismic events, trace gases, etc.



Coordination of seismic event detection and observations

2

A Plan for Lunar Exploration by using Robots

Shin-Ichiro Nishida* and Sachiko Wakabayashi*
*Lunar and Planetary Exploration Program Group, JAXA, Japan

●JAXA is carrying out research and development of a mobile robot (rover) aimed at the Lunar surface exploration and human outpost construction. The target areas for outpost construction and lunar exploration are mainly in mountainous zones, and the moon's surface is covered by regolith.
● Achieving a steady run on such irregular terrain is the big technical problem for rovers. A newly developed lightweight crawler mechanism is good for driving on such irregular terrain because of its low contact force with the ground.
●The concept of a larger lunar servicing robot for later phase is shown in Fig.1.
●This paper describes composition of the robots designed for Japanese lunar surface exploration, and presents the results of study into methods of dynamics testing and analysis which are needed in their development.
●This paper also gives an overview of the SELENE follow-on lunar exploration robot and the composition of its mobility, navigation and control system. A prototype model of the SELENE follow-on lunar robot is shown in Fig.2.

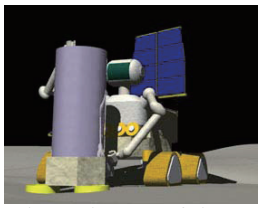


Figure 1 The concept of a larger lunar servicing robot

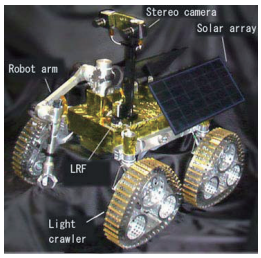


Figure 2 A prototype model of lunar rover

click to Paper

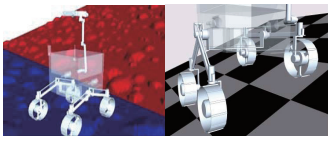
3

MoonNEXT Rover - Design of a Mobile Payload Option to Explore the Lunar South Pole

Elie Allouis*, Lester Waugh*, Simon Barraclough*, Marco Scharringhausen**, Andreas Gibbesch**
*EADS Astrium, UK
**Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany

- **The ESA MoonNEXT mission is aimed at exploring the Lunar South Pole**
- This paper investigate a rover option for this mission carrying up to 12.5kg of payload
- A number of capable rover options have been investigated with a mass up to 76 kg
- A number of innovative mass saving options have been implemented for rover and payload operations
- An innovative thermal control is proposed relying on the switching of Radioisotope heat sources
- The paper discusses the design f the subsystems and the necessary autonomy level required to perform the mission.

Stowed MoonNEXT Rover Option



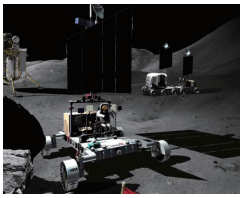
Deployed rover with reconfigurable suspension

4

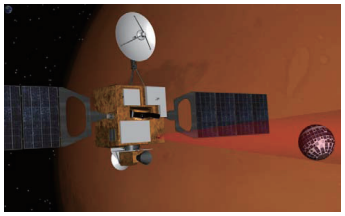
CSA Exploration Core 2009 Concept Studies: An Overview

Eric Martin, Jean-Claude Piedbœuf
Space Exploration, Canadian Space Agency, Canada
eric.martin@asc-csa.gc.ca, jean-claude.piedboeuf@asc-csa.gc.ca

- In 2009, CSA awarded 9 contracts for concept studies
- 6 studies related to robotics field, namely
  - Extraction Vehicle for In Situ Resource Utilisation
  - Canadian Contribution to the Manned Lunar Mission
  - Vision System for MSR NET
  - MEMS LIDAR for the JAXA SELENE-2 Mission
  - A Canadian Science Lander for the International Lunar Network (ILN)
  - Robotic Orion/Orbital Service Module (ROSM)
- Key objectives and overview of proposed concept presented in paper
- Many of these concepts being prototyped for demonstration in terrestrial analogue missions



MLM Rover Concept



MSR NET Laser Illumination

click to Paper

Session M2A

Spacecraft Controller

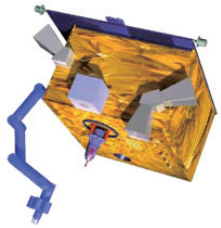
Time: 15:50-17:55
Place: Room 201

1

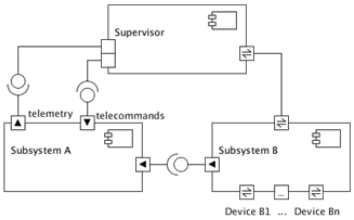
HIRSOCO – A High-Level Robotic Spacecraft Controller

Martin Stelzer, Bernhard Brunner, Klaus Landzettel, Bernhard-Michael Steinmetz, Jörg Vogel, Gerd Hirzinger*
*DLR German Aerospace Center, Institute of Robotics and Mechatronics, Germany

- HIROSCO is a control architecture designed for On-Orbit Servicing satellites
- It proposes the segmentation of a satellite application into reusable components, called subsystems
- The supervisor is a special subsystem responsible to control, to coordinate and to monitor other subsystems
- A component framework inter-connects all subsystems and enables real-time links between them
- A demonstrator has been implemented that uses HIRSOCO within a telepresence scenario



On-Orbit Servicing satellite



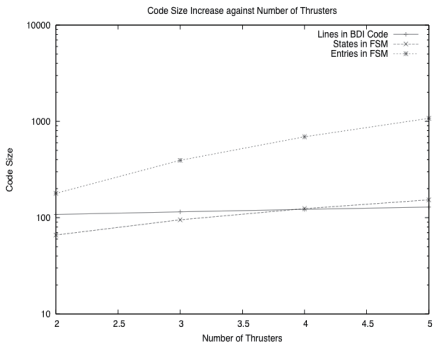
Architectural overview

2

Reducing Code Complexity in Hybrid Autonomous Control Systems

Louise A. Dennis*, Michael Fisher*, Nicholas K. Lincoln**, Alexei Lisitsa* and Sandor M. Veres**
*Department of Computer Science, University of Liverpool, UK
**School of Engineering, University of Southampton, UK

- We are investigating the control of Hybrid Systems by integrating Agent Programming Techniques with Traditional feedback controllers.
- We implemented a MatLab model of a satellite in Geostationary Orbit that was subject to thruster malfunction and possessed redundant thrusters.
- We compared the scaling of the code as the number of redundant thrusters increased when using Agent Programming and a Finite State Machine.



Comparing How Code Complexity Scale

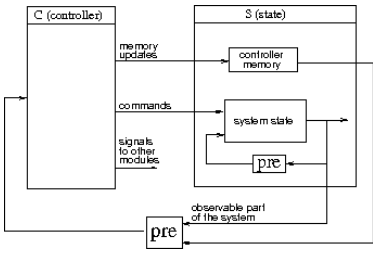
click to Paper

3

Controller Synthesis for Autonomous Systems: a Constraint-Based Approach

C. Pralet*, M. Lemaître*, G. Verfaillie*, G. Infantes*
*ONERA, the French Aerospace Lab, France

- Controller synthesis = alternative to verification
- Produces controllers valid by construction
- Controllers built for satellite subsystems, from a description of possible evolutions and requirements
- Graphical + constraint-based descriptions
- Interest: modeling flexibility + algorithmic efficiency
- Case study #1: control of a Digital Signal Processor for the detection of hot points (fires, volcanic eruptions...) at the Earth surface
- Case study #2: configuration and reconfiguration of connexions between detector lines and the mass memory of a satellite

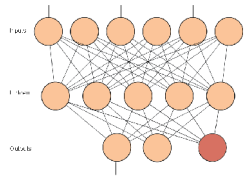


Generic control scheme

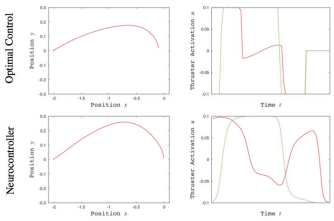
4

Evolving ANNs for Spacecraft Rendezvous and Docking

J. Leitner, C. Ampatzis, and D. Izzo
Advanced Concepts Team, ESA



Schema for the Neurocontroller



Docking Trajectories Comparison

- Evolutionary Robotics approach in space environment (2D Hill-Clohessey-Wiltshire equations)
- Introducing 'stop-neuron' for time co-evolution
- Genetic Algorithm, Optimization Problem in PaGMO

$$f = \begin{cases} 1 - \frac{t_{max} - t_d}{t_{max}} & \text{if within constraints} \\ \frac{1}{(1+\phi)(1+d)(1+s)} & \text{otherwise} \end{cases}$$

- Simulation: integration of HCW equations using the ANN (thruster) output
- Aim: to generate a state-feedback (reactive) controller
- Comparison with optimal control (time-feedback)
- Future: extending to more adaptive and robust control, multiple spacecraft and formation flying

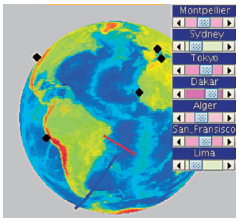
click to Paper

5

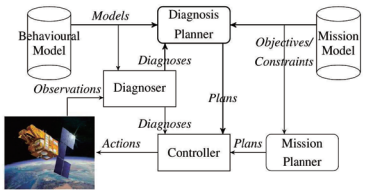
An AO*-like algorithm implementation for Active Diagnosis

E. Chanthery*, Y. Pencolé*, and N. Bussac*
*Laboratory for Analysis and Architecture of Systems, CNRS, France
Université de Toulouse ; UPS, INSA, INP, ISAE ; LAAS ; France

- Goal: to propose algorithm that solves active diagnosis problems
- Choice: an AO*-like algorithm that should compute a conditional plan to apply in order to refine the diagnosis
- Contribution 1: adaptation of the AO* algorithm to an optimization problem with various costs and rewards
- Contribution 2: definition of a heuristic adapted to active diagnosis problem
- Contribution 3: the computational time required by the proposed planner is compatible with time constraints inherent to autonomous spatial systems
- Experiments on a module (hotspotter) of a fictive satellite



Observation Satellite



Active diagnosis capabilities integration

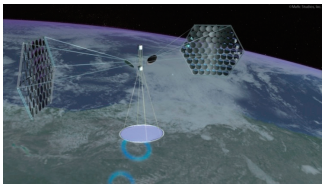
click to Paper

1

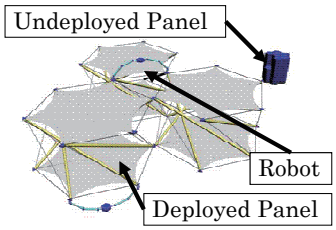
Improving Recovery Capability of Multiple Robots in Different Scale Structure Assembly

Masayuki Otani*, Kiyohiko Hattori*, Hiroyuki Sato*, and Keiki Takadama*
*The University of Electro-Communications, Japan

- **Background:** *Space Solar Power Satellite (SSPS)* assembly simulation using multiple robots which may be **broken** by several factors
- **Aim:** To propose the assembly method which can **complete** SSPS assembly in robots broken case
- **Method:** *Pair* robots cooperation focusing on **Leader-Follower relationships**
- **Approach:** Investigate this method can **recover** the robots broken situation or not
- **Evaluation:** Based on the criterion of recovery rate which indicate how the method complete assembly when the robots broken case
- **Simulation:** Changing the scale of SSPS, the number of robots, and the failure rate of robots



SSPS ©Mafic Studios, Inc.



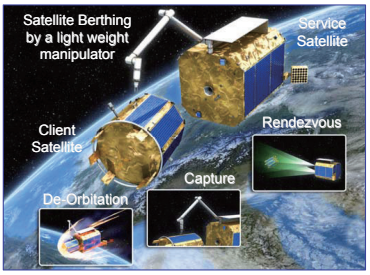
Panels and robots [Murata, 2005]

2

DEOS – The German Robotics Approach to Secure and De-Orbit Malfunctioned Satellites from Low Earth Orbits

D. Reintsema*, et.al.
*Space Agency, General Technologies & Robotics, DLR, Germany

- For maintenance, repair or refueling satellites must be captured in a safety and secure way avoiding any damage in the process.
- The German approach to serve, secure and de-orbit malfunctioned satellites is based on a semi-autono-mous robotic agent.
- DEOS (Deutsche Orbitale Servicing Mission) defines a technology demonstration and verification mission to find, verify and evaluate procedures and techniques for rendezvous, capture and de-orbiting of uncontrollable satellites using a robotic agent.
- The mission statement of DEOS defines:
  - Capture a tumbling, non-cooperative satellite;
  - Demonstrate a servicing application;
  - De-orbit the captured satellite.



DEOS – A Satellite Servicing Technology Demonstration Mission

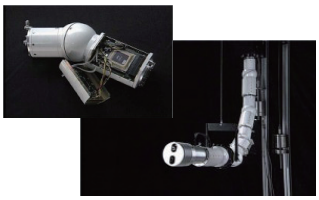
click to Paper

3

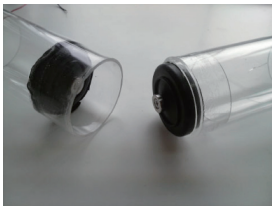
Possibilities of Module Type Robot for Space Application

Shinichi Kimura*, Yoshihiro Ozawa*, Meguru Yamauchi*
Jun Tsukahara*, Masato Terakura*
*Department of Electrical Engineering, Tokyo University of Science, Japan

- According to expansion of space mission, space robots expand their applications. Module type robot is fascinating concept to adapt various kind of task using limited resource. In previous work, we have developed module type robot for the space servicing. In the concept we have demonstrated that the module type robot has capability not only to reconfiguration according to task but also to autonomous adaptation on the partial fault.
- If we expand the module type robot in to the perfectly decentralized system and interconnect one another by magnet, we can expect another fascinating feature to the module robot, that is contact safety.
- In this paper we are going to introduce basic concept of module robots and achievement in related technologies.



Module Type Robot Prototype



Joint Mechanism Using Elastic Strucutre

4

Spatial Locomotion of Tether Based Robot

M. Yamazumi*, M. Oda**, N. Miura** , T. Ueno***
* Dept. of Mech. Sciences and Engineering, Tokyo Inst. of Technol., Japan
** Aerospace Research and Development Directorate, JAXA, Japan
***Mecha Metier, Schlumberger , USA

- Tether based robot(TBR) is a mobile robot for supporting astronauts.
- Using tethers and extendable robot arms, TBR has wide moving range and well accelerated, redundant and safe control.
- Demonstration of TBR is proposed in 2012 at ISS/JEM; Robot Experiment on JEM (REXJ)
- Research the mobile determination method for TBR
- Proposed route searching method is enable to calculate only to decide on the selection the optimized principles and target position.

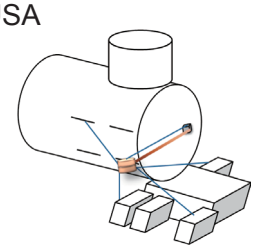


Fig.1:Tether Based Robot Image

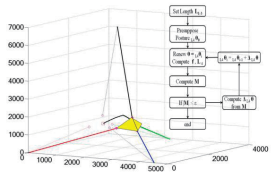


Fig.2 Simulation of Spatial Locomotion

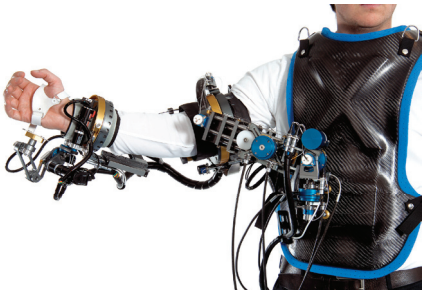
click to Paper

5

A Novel High-Performance Ergonomic Exoskeleton for Space Robotic Telepresence

A. Schiele*, H.-P. Seiberth**, P. Klaer** and G. Hirzinger***
*Telerobotics & Haptics Laboratory, ESA
**University of Applied Science Kaiserslautern, Germany
***Institute of Robotics & Mechatronics, German Aerospace Centre, DLR,

- 3rd generation exoskeleton haptic device
- 6.2 kg, fully wearable & portable design.
- Ergonomic: Interaction with 5th – 95th %-ile US males without needing adjustment of structure.
- High-performance joint-based torque control.
- Optimized for human performance to:
  - generate low interface torques.
  - be transparent as much as possible.
  - be extremely power-dense.
  - be easily donned and doffed.
  - be intuitive to use.



The X-Arm-2 Haptic Exoskeleton

click to Paper

Session M2C Visual Odometry and Navigation

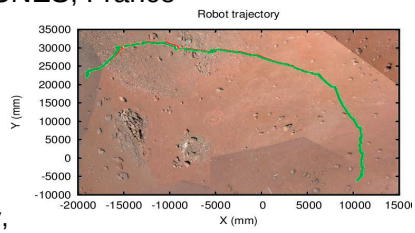
Time: 15:50-17:55
Place: Room 206

1

Vision-Based Motion Estimation for the ExoMars Rover

F. Souvannavong*, C. Lemaréchal*, L. Rastel**, and M. Maurette**
*Magellium, France
**The French Space Agency, CNES, France

- Visual motion estimation is a key module of localization systems embedded on planetary exploration rovers,
- We present a double loop architecture of a VME function designed for the ExoMars mission :
  - The first loop insures the short range accuracy, i.e. 0m->5m, at the frequency required be the mission, i.e. 0.1Hz,
  - The second loop insures the long range accuracy, i.e. 100m, by including accelerometers data and a bundle adjustment, invoked at 0.01Hz.
- Experiments on real data are given to assert that performances of the proposed system answer to the ExoMars mission needs.



Executed trajectory

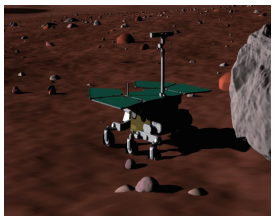
LocCams on IARES

2

Mars Visual Simulation for ExoMars Navigation Algorithm Validation

M. McCrum*, S. Parkes*, I. Martin* and M. Dunstan*
*Space Technology Centre, University of Dundee, Scotland, UK.

- Generate images of a virtual Mars-like environment.
- Use to test rover vision-based navigation algorithms.
- Based on Mars planetary science literature.
- Validated by recreating Mars Exploration Rover images.
- Includes rocks, surface reflectance, atmospheric dust, rover vehicle, dynamic shadows.
- Extension of the PANGU planet surface simulation software.
- Straightforward way for autonomy researchers to generate high-quality test images.



Rover and dynamic shadows.

Spirit image recreation.

click to Paper

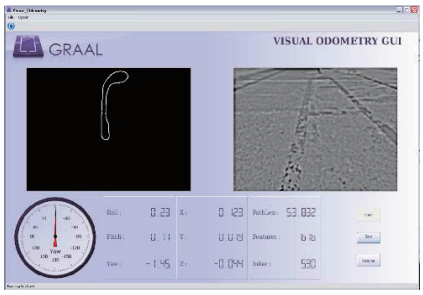
3

A Study on Planetary Visual Odometry Optimization: Time Constraints and Reliability

E. Zereik*, D. Ducco*, F. Frassinelli* and G. Casalino*
*DIST, University of Genoa, Italy

- Planetary visual odometry is very important for rover autonomous navigation.
- Vision is not badly affected by slippery or hard terrain as other sensors (i.e. wheel odometry).
- NASA's MER and MSL missions already considered visual odometry for motion estimation but they employed it in a **"stop-and-go"** manner.
- At GRAAL Lab we developed a very **accurate**, **continuous** and **faster** visual odometry module.
- Both **outdoor** and **indoor** tests were conducted, with two different mobile platforms.
- Tests showed an estimation error of **less than 1%** of the executed rover path for all performed experiments.

Rovers used for indoor and outdoor tests



Closed rover path estimated by our algorithm

4

Comparative Analysis of Localisation and Mapping Techniques for Planetary Rovers

K. Shala and Y. Gao
Surrey Space Centre, University of Surrey, UK

- Analysis of **Simultaneous Localisation and Mapping (SLAM)** techniques for application on planetary rovers: Extended Kalman Filter (EKF), Extended Information Filter (EIF), Rao-Blackwellised Particle Filter (FastSLAM).
- Analysis of **accuracy** and **computational cost** on **different trajectory types** in a representative **landmark-based, low frame rate** scenario.
- Results: EIF outperforms other algorithms. FastSLAM exhibits low robustness and accuracy especially on goal-oriented trajectories.
- **Information Filters are a promising technique for future autonomous planetary rover navigation.**

	EKF	EIF	FastSLAM
Path accuracy			
Random paths	+	+	–
Circular paths	+	+	–
Goal-oriented paths	+	+	—
Map accuracy			
Random paths	+	++	–
Circular paths	+	++	–
Goal-oriented paths	+	++	—
Computation Time			
Total	–	+	–
Prediction	+	–	++
Update	—	++	—
Optimal Number of Landmarks	60-90	100-130	> 100

Evaluated results obtained for the different algorithms.

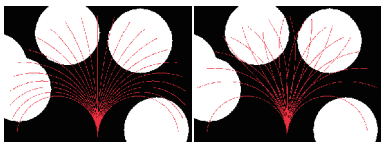
click to Paper

5

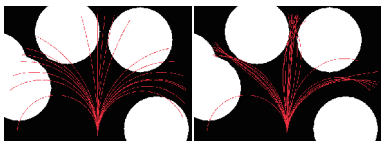
Path Set Relaxation for Mobile Robot Navigation

Philipp Krüsi*, Mihail Pivtoraiko**, Alonzo Kelly**,
Thomas M. Howard***, and Roland Siegwart*
*Autonomous Systems Lab, ETH Zurich
**Robotics Institute, Carnegie Mellon University
***Jet Propulsion Laboratory, California Institute of Technology

- Autonomous navigation and goal acquisition for mobile robots based on two-tier navigation architecture (local and global planner).
- Relaxation: Optimization of a set of (local) motion alternatives (path set) for the perceived environment, based on cost gradients.
- Two types of motion primitives considered: constant curvature arcs and clothoids.
- Simulation experiments show that:
  - Relaxed path sets lead to safer navigation.
  - Path sets composed of clothoids improve planner performance compared to arcs, both with and without relaxation.



fixed arcs fixed clothoids



relaxed arcs relaxed clothoids

click to Paper

1

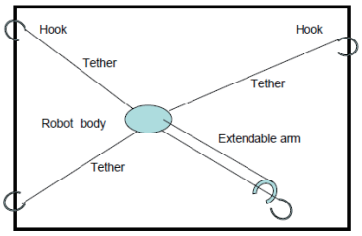
REX-J, Robot Experiment on the ISS/JEM to demonstrate the Astrobot's locomotion capability

Mitsushige Oda[1)], Masahiro Yoshii[1)], Hiroki Kato[1)], Atsushi Ueta[1)], Satoshi Suzuki[2)], Yusuke Hagiwara[3)], Taihei Ueno[3)]

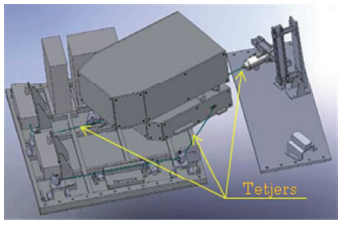
[1)] JAXA, Ibaraki, Japan, [2)] AES Co. Ltd.., Ibaraki, Japan

[3)] Tokyo Institute of Technology, Tokyo, Japan

A unique space robot named Astrobot (Astronaut + Robot) is being developed and will soon be demonstrated on the International Space Station KIBO. The Astrobot can move on the surface of the space station using tethers. Tethers will be fixed to handrails by the extendable robot arm. Then by controlling length of tethers, the Astrobot can move on the surface of the space station



Principle of Astrobot's Locomotion



REXJ onboard experiment system

2

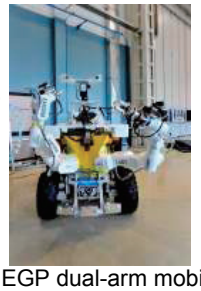
EVA Crew Assistant Supporting Astronauts in Space Missions: Autonomy and Cooperation

E. Zereik*, A. Sorbara**, A. Merlo**, G. Casalino* and F. Didot***

*DIST, University of Genoa, Italy

**Thales Alenia Space, Turin, Italy

***ESA/ESTEC, Noordwijk, The Netherlands



EGP dual-arm mobile manipulator

- EGP, a dual-arm mobile manipulator employed as a robotic crew assistant for space missions.
- **Autonomy** (EGP executes by itself operations hard or dangerous to humans) and **Cooperation** (help in tasks difficult to be performed by man on his own).
- Autonomous grasping task achieved through vision and force feedback.
- Cooperative tasks led by astronauts (EGP commanded through force feedback).
- **Coordination** among rover and arms through an algorithm based on **Dynamic Programming**.
- Performed tests in EGP demonstration scenario highlighted reliability and effectiveness of such a system.

EGP and Lander in the demonstration scenario

click to Paper

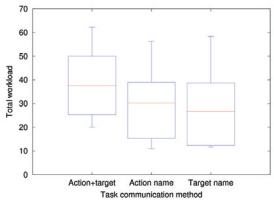
3

Human-Human Inspired Task and Object Definition for Astronaut-Robot Cooperation

Heikkilä S.*, Halme A.*, and Schiele A.**
* Automation Technology Laboratory, Aalto University, Finland
** Automation and Robotics Section, ESA, The Netherlands

- The goal of the research is to study astronaut-robot task communication for planetary surface missions.
- The approach in the paper is to mimic the human capability to understand possibilities to act on objects, i.e. object affordances.
- A test user campaign is performed in an astronaut-robot geological exploration context.
- The test persons interact with a fully autonomous centauroid robot called WorkPartner.
- The communication with action and object names are shown to decrease the test persons' workload and introduce error tolerance compared to traditional action with target based communication.

WorkPartner with a test person



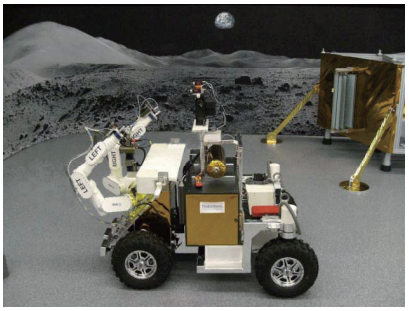
NASA TLX workload box plot

4

Integrated autonomous navigation in a large planetary exploration and service rover

A.Medina*, L.Mollinedo*, F.Gandía*, C.Pradalier**, G.Paar***, E.Pensavalle****, F.Didot*****, P.Schoonejans*****
* GNC Department, GMV, Spain
** ASL , ETHZ
*** Institute of Digital Image Processing, JR
**** Eurobot&ISS Payloads, TASI
***** ERA Project Office, ESA

- **Eurobot Ground Prototype** (EGP) is an **European Space Agency** (ESA) project.
- European industrial consortium lead by Thales Alenia Space Italia.
- **GMV** as leader of the mobile platform "**EGP-Rover"** subcontracting:
  - ASL - Technical University of Zurich (ETHZ)
  - Institute of Digital Image Processing - Joanneum Research (JR, Austria)



click to Paper

5

Prototype Development of an Operator Situational Awareness and Navigation Aid for Manned Planetary Vehicles

C. Langley*, M. Nimelman*, R. Mukherji*, R. L'Archevêque**, P. Milgram***
* MacDonald, Dettwiler and Associates (MDA), Brampton, Canada
** Canadian Space Agency (CSA), Saint-Hubert, Canada
*** University of Toronto, Toronto, Canada

- The Rover Operator Situational Awareness and Navigation Aid (ROSANA) supports operation of a lunar surface vehicle under all lighting conditions.
- Human Factors analysis was used to derive the information requirements for lunar vehicle operations, which drove the design of the display.
- Innovative technologies include illumination-invariant situational awareness, suggested path planning, and real-time map-based localization.
- A prototype of the ROSANA system was field tested on the NASA Lunar Electric Rover (LER) at Black Point Lava Flow, Arizona, USA

Nighttime test on the NASA LER

ROSANA display during daytime testing

click to Paper

back

Digest and paper

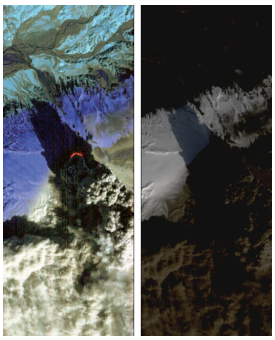
(Tuesday, August 31, 2010)

1

A Increasing the Science Return of the EO-1 Mission: A Case Study of the R5 Automated Planning Upgrade

S. Chien*, D. Tran*, G. Rabideau* , S. Schaffer, D. Mandl**, S. Frye**
*Jet Propulsion Laboratory, California Institute of Technology, USA
**Goddard Space Flight Center, USA

- A timeline-based automated scheduling system (called R5) has been deployed to schedule EO-1 operations.
- This scheduler has enabled:
  - > 40% increase ins scenes scheduled per week for an estimated value created of millions of dollars US
  - Is shown to produce schedules within 15% of an optimal upper bound
  - Increased operational flexibility to enable more just in time tasking



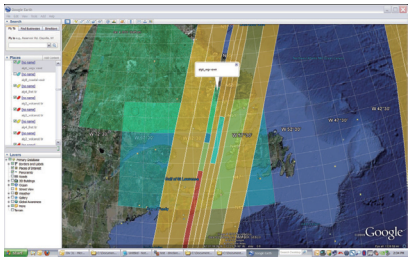
EO-1 Hyperion imagery of Eyafallajökull volcano 17 April 2010 acquired by R5 automated tasking

2

Onboard Processing for Low-latency Science for the HyspIRI Mission

S. Chien*, D. Mclaren*, G. Rabideau*, D. Silverman*, D. Mandl**, J. Hengemihle**
*Jet Propulsion Laboratory, California Institute of Technology, USA
**Goddard Space Flight Center, USA
*** Microtel LLC, USA

- A Direct broadcast systems is baselined for low-latency science and applications HyspIRI VSWIR and TIR instrument data
- These instruments will produce 20x-80x more data than can be downlinked in real-time
- Onboard processing will enable relevant data products to be produced onboard and downlinked in this reduced link
- Ground-based automated planning will command this onboard product generation based on ground regions of interest defined by science
- An initial prototype has been developed and is under evaluation



Sample instrument swaths and intersecting regions of interest in ground planning tool for HyspIRI onboard product generation

click to Paper

3

Benefits from Innovative Tools for Diagnostic and Planning in Mission Operations

A. Donati* et all.
*Advanced Mission Concepts and Technologies Office, ESA

- **Goal**: validate new operations concepts for increased on board autonomy and for ground capabilities to agglomerate and process a huge amount of downlinked data
- **Domain**: Mission Planning & Scheduling and Mission Monitoring & Diagnostic
- **Method**: deployed prototype tools in mission control for extended operational validation applied to use-cases of current flying missions
- **Paper discussion** on the tools' operational impact and on the expected trend for the future.
- **Justification**: challenging missions such as interplanetary probes, complex scientific missions and a constellation of earth observation missions

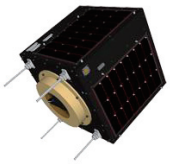
Main Control Room
ESA/ESOC

4

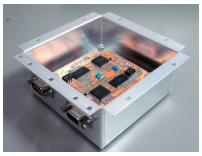
Robustness of Bit Inversion in Registers and Acceleration of Program Evolution in On-Board Computer

Tomohiro Harada*, Masayuki Otani*, Yoshihiro Ichikawa*, Kiyohiko Hattori*, Hiroyuki Sato*, and Keiki Takadama*
*The University of Electro-Communications, Japan

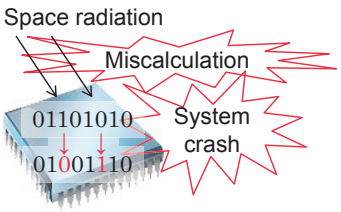
- We propose **Tierra-based OBC** which evolves the computer programs through the bit inversion.
- **Tierra-based OBC (University OBC: UOBC)** is loaded in "**SHIN-EN" (UNITEC-1)** launched to Venus as the piggyback of "AKATSUKI" (PLANET-C).
- The experiments of Tierra-based OBC are conducted on SHIN-EN in actual bit inversion in space.
- This paper presents;
  1. Robustness of Tierra-based OBC in the register bit inversion
  2. New method to accelerate the program evolution.



UNITEC-1



UOBC



Bit inversion

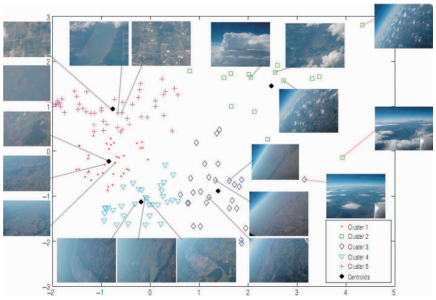
click to Paper

5

Onboard Clustering of Aerial Data for Selective Data Return

David S. Hayden*, Steve Chien*, David R. Thompson*, Rebecca Castano*
*Jet Propulsion Lab, California Institute of Technology

- In remote space exploration, far more sensor data can be collected than can typically be returned for human observation.
- Computationally efficient, unsupervised algorithms running onboard the spacecraft are proposed that can improve science return by downlinking a broad sample of remotely-sensed data, samples biased to a particular science event, or outliers.
- Early work demonstrates that remotely-sensed images can be autonomously grouped in a way that more closely matches how an expert would group them than either random or periodic sampling.



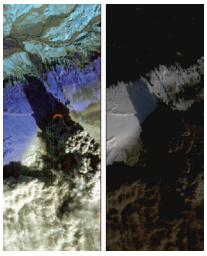
Subpolynomial-time clustering of aerial imagery with cluster representatives (gray lines) and outliers (red lines). Clusters exhibit clear semantic distinction

6

A Multi-agent Space, In-situ Volcano Sensorweb

S. Chien*, D. Tran*, J. Doubleday*, A. Davies*, S. Kedar* , F. Webb*,
G. Rabideau* , D. Mandl**, S. Frye**, W. Song***, B. Shirazi***, R. Lahusen****
*Jet Propulsion Laboratory, California Institute of Technology, USA
**Goddard Space Flight Center, USA
*** Washington State University, USA
**** United States Geological Survey, USA

- An agent oriented space, in-situ sensorweb is being used to operationally monitor volcanoes worldwide.
- The Space component uses Terra, Aqua, EO-1 and other satellites
- The in-situ component uses sensors at a number of volcanoes worldwide including Mt. Saint Helens, Mt. Erebus, and others.
- Space assets are automatically tasked to observe when events are detected by the network.
- In-situ sensors are reconfigured in response to alerts as well (re-allocation of bandwidth).



EO-1 Hyperion imagery of Eyafallajökull 17 April 2010 acquired by sensorweb

Spider sensor at Mt. St. Helens

click to Paper

Session T1B On-Orbit Service and Tele-Robotics

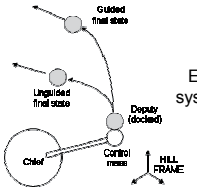
Time: 10:10-12:40
Place: Room 202

1

Release Guidance Analysis Using Charged Formation Flying for On-Orbit Servicing

Paul Iliffe*, Saburo Matunaga**
*Ph.D. Student, Laboratory for Space Systems, Tokyo Institute of Technology, Japan
**Associate Professor, Tokyo Institute of Technology, Japan

- Satellite Coulomb formation stands as a possible method of realising efficient on-orbit servicing.
- This paper details the controlled deployment of a deputy satellite from its docked position to a target path for the purpose of on-orbit servicing.
- Feedback control and a series of sequential elliptical guidance paths allow for accurate deployment.
- The results show that, before convergence to the target path, two rotations of the deputy satellite about the chief satellite yield the most accurate positional outcome.



Example of system motion

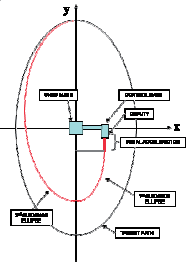


Illustration of deployment stages

2

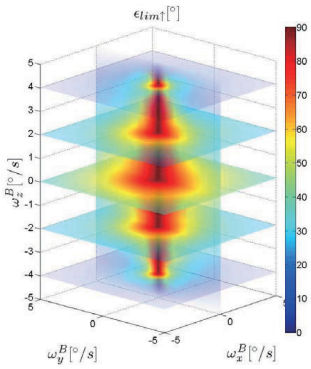
Autonomous Control of Operative Constrains during Real-Time Teleoperation of Space Robots

Markus Pietras, Florian Rems, and Ulrich Walter

Institute of Astronautics (LRT), Technische Universitaet Muenchen (TUM), Munich, Germany

- Problem: unpredictable, interactive control of the space robot during real-time teleoperation
- Operative constrains like communication antenna pointing violated as a result from the unplanned change in the space robot's state
- => Signal losses, instrument damage or even los of the spacecraft.

- Proposed Autonomous Boundary Avoidance to avoid prohibite states of the spacecraft while still al allowing real-time teleoperation



Visualization of pointing Limit

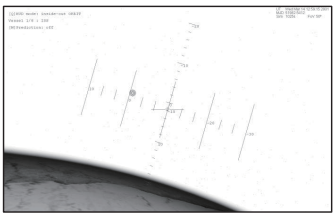
click to Paper

3

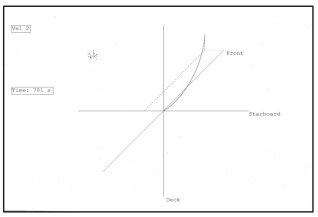
Experimental Head-Up Display for Space Telerobotics

M. Wilde, J.-P. Hamacher, U. Walter
Institute of Astronautics, Technical University Munich, Germany

- Space environment foreign and unintuitive compared to everyday environment
- Telerobotics in space pose challenges to human perception and spatial modeling capabilities
- No natural references available for spacecraft position and orientation
- Head-Up Display to provide artificial attitude references
- HUD includes trajectory prediction for capture & docking maneuvers
- Implemented for Orbiter spaceflight simulator and as stereo video overlay



Inside-out HUD



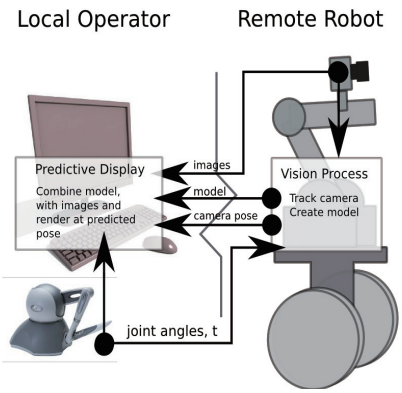
Relative trajectory prediction

4

Predictive Display from Computer Vision Models

Martin Jagersand, Adam Rachmielowski, David Lovi, Neil Birkbeck, Alexjandro Hernandez-Herdocia, Azad Shademan, Dana Cobzas, Keith Yerex
University of Alberta
www.cs.ualberta.ca/~vis

- Tele-robotics, particularly manipulation, suffers from transmission delays in regular video.
- In Predictive Display the operator motions are rendered immediately from this model, before delayed video arrives.
- Meanwhile the delayed video is used to incrementally add 3D structure and texturing key frames to the model.
- In a robot 6DOF alignment task completion times using predictive display is comparable to native, no delay, while delayed video increases completion times 48%



PD System using on-line 3D modeling from video

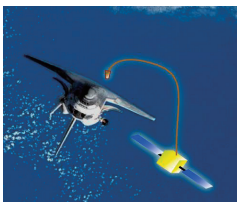
click to Paper

5

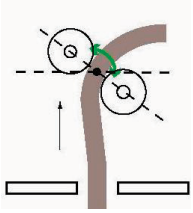
Development of Improved Morphable Beam Device with Rotation Based Shaper

Shintaro Mizunuma*, Nobuhiko Kisa*, and Saburo Matunaga *
* Department of Mechano-Aerospace Engineering
Tokyo Institute of Technology

- Morphable Beam Device(MBD) is small and light-weight system which have possibility to alternate ordinary robotic arm.
- MBD is suitable for a visual inspection system of small satellites.
- The new test model of MBD has developed to examine the new shaper mechanism based on rotation.
- The new mechanism is superior to the previous one in terms of size, mass and controllability.
- New mechanism is inferior to the previous mechanism in terms of controlling accuracy.
- The conclusion is that new mechanism is better in the certain cases of practical MBD use.



MBD attached to satellite



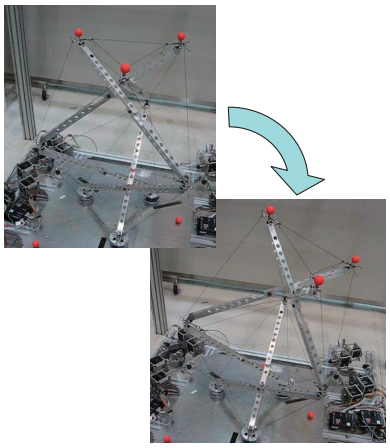
New Shaper concept

6

Deformation of Tensegrity Structure Using Tendon Actuators

Yusuke Hagiwara*, and Mitsushige Oda**
*Mechanical and Aerospace Engineering, Tokyo Institute of Technology, Japan
**Aerospace Research and Development Diractorate, JAXA, Japan

- The tensegrity structure consists of some rigid bars and flexible wires, and can maintain its shape when the members of the structure is balanced.
- The tensegrity structure is studied to use as the deployable space structure, and the space manipulator.
- To transform the structure, it is suggested to be used wires as actuators and connected wires for reducing the number of actuators.
- Numerical analyses for form-finding and for obtaining deformation paths are conducted.
- A transforming experiment is conducted and leaning motion is demonstrated.



Leaning motion of the tensegrity structure

click to Paper

Session T1C — Rover Design and Mobility

Time: 10:10-12:40
Place: Room 206

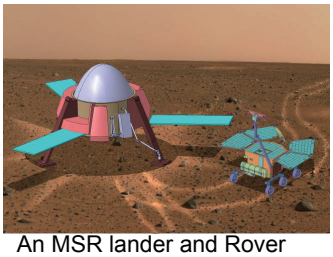
1

End-to-end Design of a Robotic System for Collecting and Transferring Samples on Mars

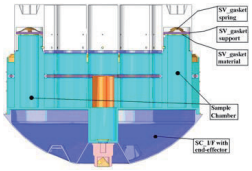
E. Allouis*, T. Jorden*, N. Patel*, S. Senese**, P. Magnani**, R. Spörri***, K. Kapellos†, R Wiesendanger ††, G. Visentin†††

* EADS Astrium, Future Programmes, UK
** Selex Galileo, Italy
*** RUAG Aerospace AG, Switzerland
† Trasys SA, Belgium
†† EPFL, Switzerland
††† Automation and Robotics Section, ESA

- This study investigated the Mars Surface Sample Transfer and Manipulation (MSSTM) chain to collect, encapsulate and transfer samples to the return vehicle
- The study investigated a large design space before selecting a baseline architecture:
  - •sample vessels integrated into a sample container,
  - •a dedicated capping mechanism
  - •A 6Dof transfer arm with vision-based control
- The design of the critical elements has been performed and are now being breadboarded to further prepare the critical elements of a future Mars Sample Return Mission



An MSR lander and Rover



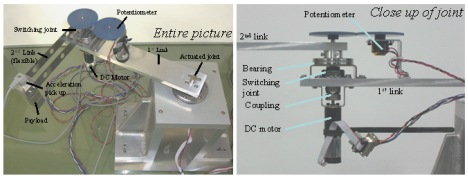
Sample Container and Vessels

2

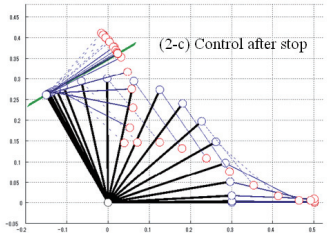
Control for Space Robotic Manipulator with Passively Switching Free Joint to Drive Joint

M. Otsuki*, and T. Kubota*
*Institute of Space and Astronautical Science, JAXA, Japan

- The proposed manipulator has double features of UAM and general full-actuated manipulator
- It can dramatically reduce the power consumption for its motion and the vibration in the flexible link
- This result is also implementation of relax motion for a manipulator system such as animal manipulation
- Its application is wide-ranging, e.g., substitution of crane wire, elevator rope, and tether in satellite, planetary sampling tool, and positioning device in orbit



The entire picture of the experimental setup and the close up of the switchable joint



The profiles of the experimental results

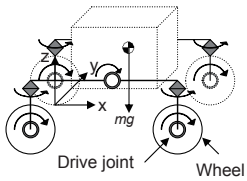
click to Paper

3

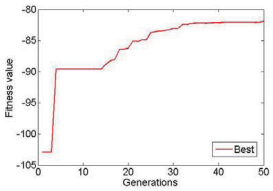
Conceptual Rover Design by an Integrated Optimization Process

Aravind Seeni, Bernd Schäfer, and Gerd Hirzinger
Institute of Robotics and Mechatronics
German Aerospace Center (DLR), Germany

- A method that helps rapid system-level designing of rovers is demonstrated.
- Genetic Algorithm, a heuristic, numerical optimization method is used as optimizer to search for solutions in the decision space
- Simplified multibody model of a four-wheeled rover vehicle developed using Dymola/Modelica
- Simulation performed to estimate rover states and performance criteria
- Mechanical and control parameters are tuned to solve a set of constraints by Genetic Algorithm



Dynamics model of vehicle



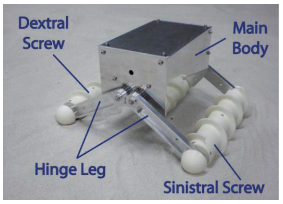
Example of GA convergence of fitness function

4

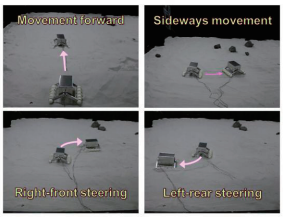
Modeling and Analysis on Exploration Rover with Screw Drive Mechanism over Loose Soil

Kenji Nagaoka* and Takashi Kubota**
*The Graduate University for Advanced Studies (Sokendai), Japan
**Institute of Space and Astronautical Science, JAXA, Japan

- A novel rover driven by Archimedean screw units, named Screw Drive Rover, is proposed for secure locomotion on loose soil such as lunar regolith
- Empirical mobility performance of the Screw Drive Rover prototype is also presented
- Mathematical modeling of the interaction between the soil and the screw unit based on conventional terramechanics models is developed
- Three-dimensional helical motion of a screw blade is considered in the interaction model
- Characteristics of the proposed model are discussed by simulation analyses
- Evaluation of the tractive effort of the Screw Drive Rover model is conducted as a synthesis analysis



Screw Drive Rover



Diverse locomotion performed by Screw Drive Rover

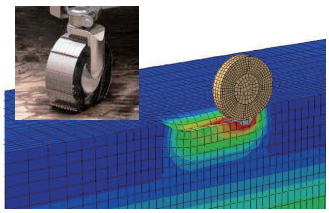
click to Paper

5

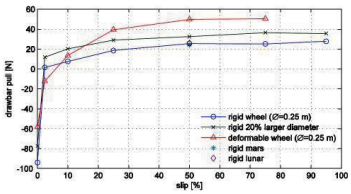
Assessment of Tractive Performances of Planetary Rovers with Flexible Wheels Operating in Loosely Packed Soils

J.P. Pruiksma*, J.A.M. Teunissen*, G.A.M. Kruse*, M.F.P. van Winnendael**
*Deltares, Delft, The Netherlands
** Automation and Robotics Section, European Space Agency

- 3D Finite Element Modeling of wheel-soil interaction, for rigid and flexible driving wheels operating on compressible soils under Terrestrial, Martian and Lunar gravity conditions, wide range of slip.
- Based on Critical State Soil Mechanics models
- Expected to be more adequate than semi-empirical approaches for prediction of tractive performances on Mars, Moon, and for related design tradeoffs.
- Enables extrapolation of Terrestrial tractive performance test results to Martian, Lunar conditions
- Pilot Project, using ESA's ExoMars Rover flexible wheel design and estimated properties of one Martian soil simulant (very fine sand).



Model of flexwheel and soil



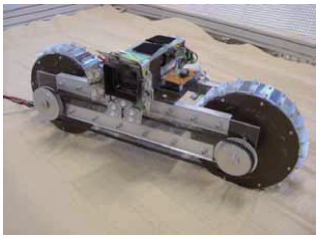
Example of a result: Drawbar Pull

6

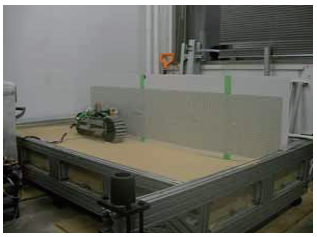
Traveling Performance Evaluation for Planetary Rovers on Weak Soil

Masataku Sutoh, Junya Yusa, Keiji Nagatani, Kazuya Yoshida
Department of Aerospace Engineering, Tohoku University, Japan

- In lunar/Martian surface explorations, planetary rovers play a significant role.
- Because of wheel slippage, the wheels of rovers may get stuck in loose soil.
- It is vey important to consider wheel parameters for rovers to accomplish a given navigation mission.
- The wheel diameter and width are considered to be dominant factors of traversability of wheels.
- We performed slope climbing test using a two-wheeled testbed in different wheel parameters and carried out numerical simulations.
- We report the experimental and simulation results, and discuss the influence of the wheel parameters on the traversability.



Two-Wheeled Testbed



Slope Climbing Test

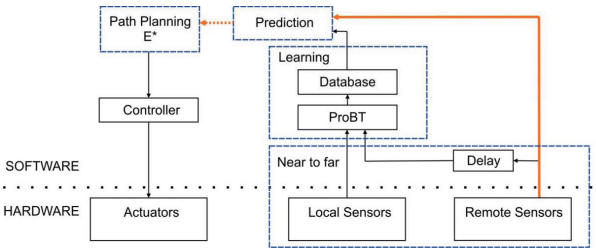
click to Paper

1

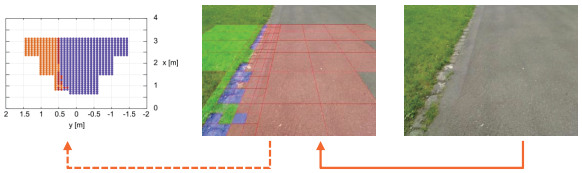
RTILE - Adaptive rover navigation based on online terrain learning

A. Krebs, C. Pradalier, and R. Siegwart
Autonomous Systems Lab, ETHZ, Switzerland

- RTILE (*Rover-Terrain Interaction Learned from Experiments*) allows a rover to **learn** online its **interaction** model with the ground.
- The model built can then be used to **predict** the interaction ahead of the rover.
- The rover **trajectory** is then **optimized** accordingly.
- The paper focuses on the **rating process** of the different terrains for the E* path planner.



RTILE approach overview



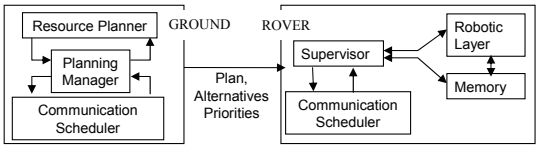
Rover-terrain interaction characteristics prediction

2

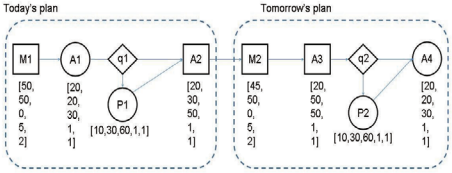
Communication Scheduling and Plan Revision for Planetary Rovers

I. Musso*, R. Micalizio**, E. Scala**, G. Martucci*, E. Pigozzi*, P. Rosazza*
*Advanced Logistics Technology Engineering Center, Torino, Italy
** Dipartimento di Informatica, Universita' di Torino, Torino, Italy

- Communication constrains are severe in case of scientific missions requiring many feedbacks from Ground Control Centre
- An integrated system for Rover resources planning and communication scheduling is proposed
- Conditional plan provides Rover with simplified autonomous capabilities demanding low computational power and maintaining executive control at Ground
- Proposal to adopt capabilities for Rover plan revision with two levels of autonomy: high (communication scheduling onboard) and low (revision of one day plan only)
- Analysis of the onboard revision effects on Rover and Ground activities plans



Integrated planning system architecture



Conditional Rover plan and tasks properties

click to Paper

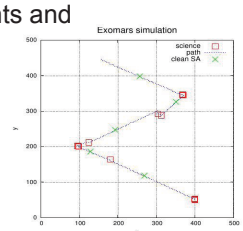
3

Hybrid Architecture Agent for Planetary Surface Exploration

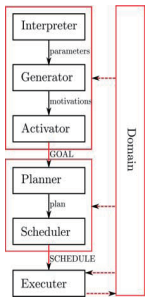
POLITECNICO DI MILANO
Aerospace Dep.

Francesconi P.*, and Lavagna M.*
*Politecnico di Milano, Dipartimento di Ingegneria Aerospaziale, Italy

- Hybrid architecture agent made of a Goal Manager, Planner/Scheduler, Executer, and a static Knowledge Base
- Goal Manager: Interpreter, translates the domain into parameters values; Generator solves a MADM problem to evaluate the intensity of each goal; Activator assembles the goal and call the PS
- Planner/Scheduler: this module generates a schedule using a Graphplan-like algorithm coupled with a Simple Temporal Network, to reach the consistency of both metric temporal constraints and resource allocation
- Tested on different, increasing in complexity, ExoMars rover-like simulated scenarios



Rover path



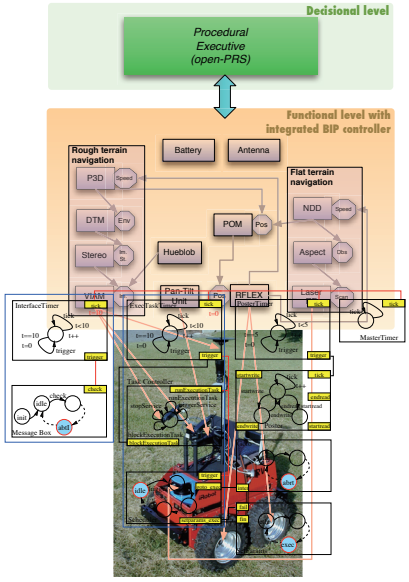
Agent framework

4

"Rock Solid" Software: A Verifiable and Correct-by-Construction Controller for Rover and Spacecraft Functional Levels

Saddek Bensalem† Lavindra de Silva‡ Matthieu Gallien† Félix Ingrand‡ Rongjie Yan†
†Verimag/CNRS, Grenoble I University, France
‡LAAS/CNRS, Toulouse University, France

- Beyond the "classical" software engineering requirements
- Modular development: GenoM
- Component based design: BIP
- Produce a complete BIP model of a GenoM based functional layer.
- Rover and Spacecraft controller correct-by-construction.
- BIP Engine enforces model properties at run-time.
- D-Finder : a tool to detect deadlock in the model.



click to Paper

Session T2B Operation and Support Tool

Time: 14:00-15:40
Place: Room 202

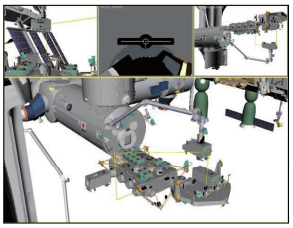
1

Development and Realtime Monitor of JEM Robotics Operation Ground Observatory (ROGO)

Yoshiyuki Kitajima*, Hiroaki Hattori*, Hiroshi Ueno**, and Shinobu Doi**
*Mitsubishi Space Software, Co., Ltd., Japan
**Japan Aerospace Exploration Agency, Japan

- ROGO has been developed to support the operations of JEM Remote Manipulator System (JEMRMS) in the International Space Station (ISS).
- The main functions of ROGO are the followings.
  > Telemetry display specialized for robotics task
  > 3D graphics which reflects real-time telemetry data
  > Image processing for payload berthing
- COTS software was incorporated to shorten the development period.
- ROGO has been used for real-time monitoring of JEMRMS and contributed to the accomplishment of the missions.

Telemetry display



3D graphics

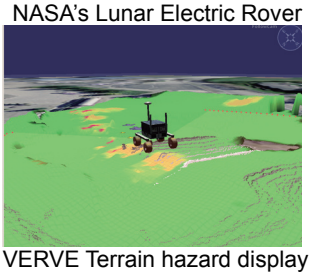
2

High Speed Lunar Navigation for Crewed and Remotely Piloted Vehicles

L. Pederen*, M. Allan*, V. To*, H. Utz*, W. Wojcikiewicz**, C.Chautems***
*Intelligent Robotics Group, NASA ARC, USA
**Humbold University, Germany
***ETH, Switzerland

- High speed (2-3m/s) lunar autonomous and tele-operated navigation
- Lunar Electric Rover (LER) pilot hazard display
- Lidar sensor analysis
- Lunar terrain hazard detection

NASA's Lunar Electric Rover



VERVE Terrain hazard display

click to Paper

3

Initial operation of the Small Fine Arm of JEMRMS

Hiroshi Endo*, Shinobu Doi** and Hiroshi Ueno**
* JEM Operation Project Team, JAXA, Japan (Current Electromechanical Systems Design Section, Hitachi-GE Nuclear Energy, Ltd. Japan)
**JEM Operation Project Team, JAXA, Japan

・The Japanese Experimental Module (JEM), "Kibo" is one of the international Space Station (ISS) elements.
・The Small Fine Arm (SFA) is one of subsystem of JEM Remote Manipulator System (JEMRMS), launched by HTV (H-II Transfer Vehicle) last year.
・Assembled in JEM by IVA and passed through the JEM Air lock for the first operation in space.
・Grappled by the Main Arm (MA) of JEMRMS, finally stowed to the SFA Stowage Equipment (SSE) on the JEM Exposed Facility (JEF) after initial check-out in March 2010.
・SFA unique function, initial operation and future plan are presented.

SFA in JEM

SFA in space

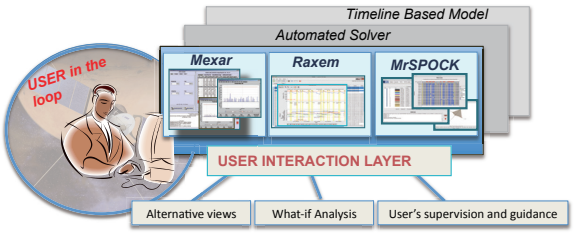
4

Pursuing Interactivity of Mission Planning Supports A Retrospective View

A. Cesta & G. Cortellessa
Institute of Cognitive Science and Technology – ISTC-CNR, Rome, Italy

Lessons Learned in designing interaction for mission planning tools at ESA

- **Smooth integration** of innovative products (*non disruptive transition to new ways of work*)
- **User supervision and guidance** (*humans stay in control and guide search*)
- **What-if analysis** and **focus on alternatives** (*to enhance human planning abilities*)
- Support to **plan management** (*better supports the complete problem solving loop*)
- **Timelines** as a means of interaction (*a powerful metaphor to support interactivity*)



The Interactive scenario pursued in our tools developed for ESA

click to Paper

Session T2C

Robotic Exploration

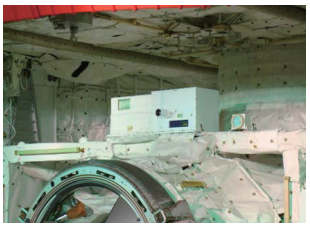
Time: 14:00-15:40
Place: Room 206

1

An Overview of Canadian Space Robotics Activities

Erick Dupuis, Yves Gonthier, Jean-Claude Piedboeuf
Canadian Space Agency

- Robotics for ISS and Shuttle, On-Orbit Servicing and Planetary Exploration
- Flight Experiments and Analogues Campaigns
  - •TriDAR Demonstration Flights
  - •Avatar-EXPLORE Teleoperation Experiments
  - •Analogue Rover Campaigns in Arctic, Mojave, Arizona and Hawaii
- Technology Development Projects
  - •Next Generation Canadarm
  - •Exploration Surface Mobility



2

Test-bed Rovers for Planetary Surface Exploration

Takashi Kubota*, Masatsugu Otsuki*, Takanobu Shimada*,
Yoji Kuroda**, and Ysuharu Kunii***

*JAXA, Japan, **Meiji University, Japan, ***Chuo University, Japan

- Test-bed rovers have been developed for future planetary exploration missions in Japan.
- This paper presents the planetary robotic exploration scenario and strategy.
- This paper presents the detail of the system configuration of the developed rovers.
- This paper also describes the detailed functions and shows the performance of the developed rovers.
- The smart manipulator is also proposed and developed for scientific observation.
- The experimental results show the effectiveness of the developed rovers.

Developed Test-bed Rovers

Smart Manipulator

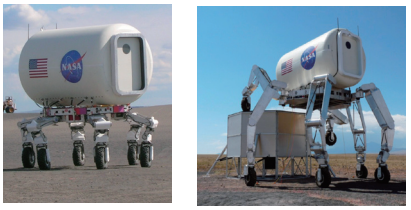
click to Paper

3

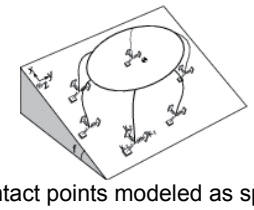
FootSpring: A Compliance Model for the ATHLETE Family of Robots

Dawn Wheeler*, Daniel Chavez-Clemente**, and Vytas SunSpiral***
*SGT, Inc, NASA Ames Research Center, USA
**Department of Aeronautics and Astronautics, Stanford University, USA
***Carnegie Mellon University, NASA Ames Research Center, USA

- **A**ll-**T**errain **H**ex-**L**imbed **E**xtra**T**errestrial **E**xplorer
  - Wheel-on-leg lunar cargo robots
  - 6 legs with 6-7 DOF per leg
  - Very compliant
- FootSpring model assumes all compliance in legs/wheels
- Predicts sag with ~2-3% error
- Allows successful off-board open-loop gait planning
- Verified on two models of ATHLETE robot



ATHLETE SDM-B (left) and T12 (right), with simulated habitat



Contact points modeled as springs

4

A Canadian Breadboard Rover for Planetary Exploration

R. McCoubrey*, J. Allport*, M. Umasuthan*, L. Oshinowo*
*Space Missions, MDA, Canada

- Six wheeled prototype of a planetary exploration chassis and locomotion subsystem, developed by MDA for the Canadian Space Agency
- Design derived from ExoMars rover prototype developed by MDA for the European Space Agency
- Adapted to support a wide range of payloads during extended field testing in analogue environments
- Generalized inverse kinematics formulation
- Testing on representative terrain demonstrated slope/obstacle climbing, point turning and crabbing
- Integration with guidance, navigation and control payload demonstrated autonomous driving
- Future work includes June 2010 Mars sample return analogue mission deployment

Canadian Breadboard Rover

Pose adjustment

click to Paper

Poster Session

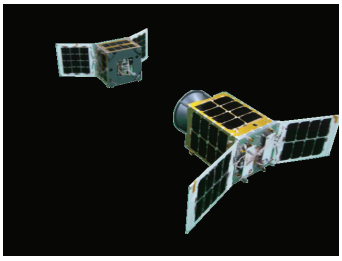
Time 16:00-17:30
Place: Room 204

1

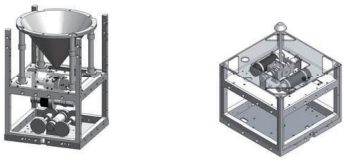
Orbital Experiment Report of Pico-Satellite KUKAI

Masahiro Nohmi*
*Faculty of Engineering, Kagawa University, Japan

- KUKAI was developed in Kagawa University and launched by the H-IIA rocket on 23 January, 2009.
- The primary objective of KUKAI is technical verification of a tethered space robot.
- The mother satellite has tether deployment system, which deploys the tether for short distance, and orbital experiment evaluated the developed system.
- The daughter satellite is a tethered space robot, and the main functions for robotic motion control were evaluated.
- Electrical power budget was analyzed based on the housekeeping telemetry data.



KUKAI Flight Model



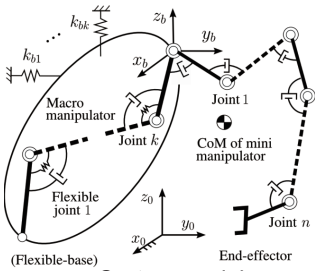
Mechanism for Tether Deployment and Robotic Mission

2

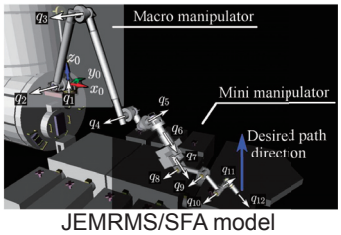
Stable Path Tracking With JEMRMS Through Vibration Suppression Algorithmic Singularities Using Momentum Conservation

N. Hara*, Y. Kanamiya** and D. Sato**
Mechanical Systems Engineering, Graduate School of Engineering,
Tokyo City University, Japan.

- A new reactionless path tracking control method for flexible-base manipulator system is addressed.
- In the neighborhood of algorithmic singularity which is due to the constraint imposed via the path tracking and vibration suppression subtask, the system not only becomes unstable but also limits the workspace of the operated robot arm.
- Simulation results demonstrate that it is possible to obtain stable and almost reactionless motion and to go through the algorithmic singularity, with the Japanese Experiment Module Remote Manipulator System (JEMRMS) / Small File Arm (SFA), which is composed of a three-DOF macro manipulator with flexible joints and nine-DOF mini manipulator.



System model



JEMRMS/SFA model

click to Paper

Poster Session

Time 16:00-17:30
Place: Room 204

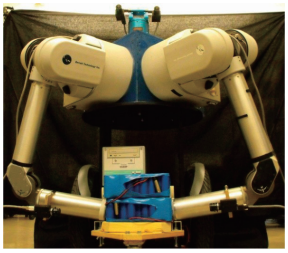
3

A Modular and Flexible Bimanipulation System for Space-Analogue Experiments

Alejandro Hernandez Herdocia, Azad Shademan, and Martin Jägersand
Department of Computing Science, University of Alberta.
Edmonton, Alberta, Canada.

- Designing is important even when the subsystems are already available.
- Off-the-shelf component integration requires no specialized engineering facilities or expertise.
- Allows to center research in algorithms for mobile manipulation independently of mechanical design.
- This approach allows broader audiences to participate in research of mobile manipulation.
- System designed to be self contained.
- Currently being developed for visual servoing and teleoperation with predictive display.

http://www.cs.ualberta.ca/~vis/robotics/spacerob.htm



Dual Arm Mobile Manipulator

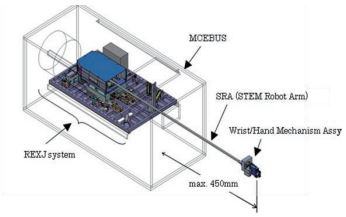
Lifting a Box

4

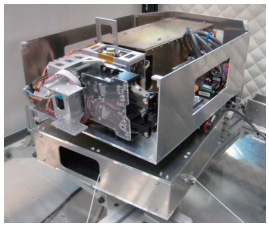
A Ground-Based Operation System for EVA Support Robot Experiments

Atsushi UETA and Mitsushige ODA
Aerospace Research and Development Directorate, JAXA, Japan

- JAXA plans to conduct a robot experiment to demonstrate locomotion strategy using tethers and an extendable robotic arm with a robotic hand on the JEM Exposed Facility of ISS, in FY 2011
- The experiment (REXJ) will be controlled remotely by a ground-based operation system in JAXA's Tsukuba Space Center
- High safety and reliability are required for the system to achieve the experiment successfully
- This paper reports a progress and challenges in development of the ground-based operation system for REXJ



REXJ 3D-CAD Model



REXJ Ground Test Model

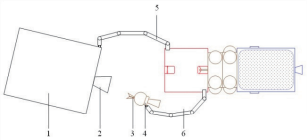
click to Paper

5

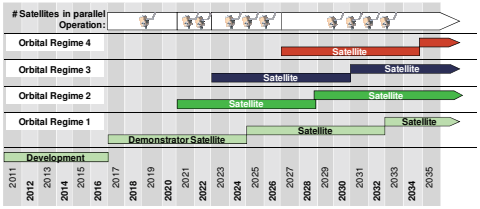
Economic Approach for Active Space Debris Removal Services

M. Loesch* and J. Kreisel**
*Astrium Satellites GmbH, Germany
**Joerg Kreisel International Consultants, Germany

- Orbital debris is a threat to satellites and astronauts
- A spacecraft concept is presented, utilizing two robotic arms to grapple with debris and install a de-orbiting device
- Modular platform: fuel and de-orbit kits are replenished via resupply operations
- Gradual deployment of a servicer fleet
- A commercially viable business approach is presented, considering various revenue mechanisms and staged investments
- Prepared by the 12th *SpaceTech* Master's Class, Delft University of Technology



Installation of De-orbit Device



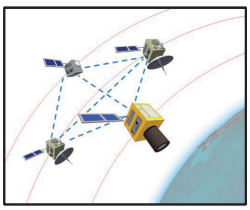
Fleet Deployment Schedule

6

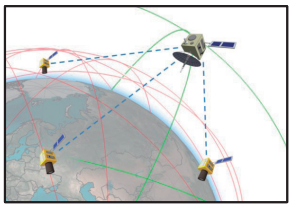
Satellite network architectures against emerging space threats

Frédéric Cristini*, Catherine Tessier*, and Eric Bensana*
*ONERA - The French Aerospace Lab, Toulouse, France

- Space systems may be subject to **emerging threats** coming from the **artificial space environment**.
- This study aims at designing intrinsically **threat-tolerant satellite systems**.
- Two different system architectures based on **specialized networked small satellites** are proposed:
  - The "**swarm constellation**" architecture
  - The "**networked constellation**" architecture
- Preliminary results show that increasing the amount of nodes in the satellite networks seems to be more efficient than simply adding redundant satellites.



The "swarm constellation" architecture



The "networked constellation" architecture

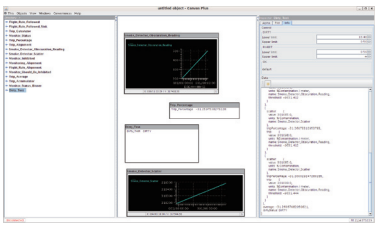
click to Paper

7

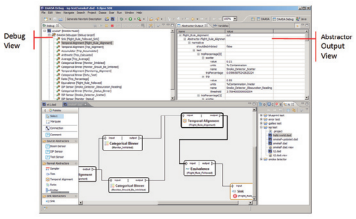
A Data Abstraction Architecture for Mission Operations

Scott Bell*, David Kortenkamp*, and Jack Zaientz**
*TRACLabs Inc., Houston Texas USA
**Soar Technologies Inc, Ann Arbor MI,USA

- Modern space system generate huge amounts of data that must be monitored by humans and software.
- To efficiently monitor these systems the data must be abstracted to reflect the trends, states and characteristics of the systems.
- The Data Abstraction Architecture allows engineers to design software processes that iteratively convert spacecraft data into higher levels of abstraction
- Data Abstractors provide the building blocks.
- A drag-and-drop editor hides the system software from the engineers.
- Tests using ISS data have been performed.



Flight controller view



Editor

8

iSAIRAS2010 Digest
Towards Operator Monitoring via Brain Reading - An EEG-based Approach for Space Applications

Elsa Andrea Kirchner*,**, Hendrik Wöhrle*, Constantin Bergatt*, Su Kyoung Kim*,**, Jan Hendrik Metzen**, David Feess*, and Frank Kirchner*,**
*Robotic Innovation Center (RIC), DFKI, Germany
**Robotics Lab, University of Bremen, Germany

- We introduce a new kind of astronaut support system based on single trial analysis of brain activity – brain reading (BR).
- BR does not directly link brain activity and the action of machine and is therefore applicable even in critical situations in space.
- An example for BR will be given (see figure 1).
- Improvements regarding training data acquisition and transferability of training, software structure and data processing flow are needed and introduced.
- We will explain and discuss first results within an experimental setup (see figure 2).

Figure 1: Brain-reading scenario

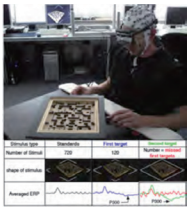


Figure 2: Experimental Setup for BR

click to Paper

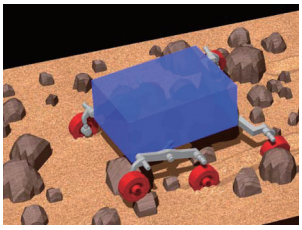
9

Advanced testbed and simulation environment for planetary exploration and mobility investigations

B. Rebele*, A. Wedler*, M. Apfelbeck*, H. Hirschmüller*, S. Kuss*, A. Gibbesch*, B. Schäfer*, G. Hirzinger*
* German Aerospace Center, DLR, Germany

- Unique combination of test and simulation environment for planetary rovers
- Design support, navigation, test and mission planning
- Automatic generation of Digital Elevation Model
- High precision tracking of rover motion
- Various sensors and measuring devices for rover performance
- Evaluation of soil properties
- MBS simulation tool including wheel soil contact modules for soft soil and rigid terrain

ExoMars breadboard in testbed



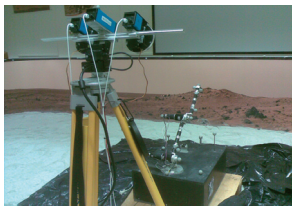
Performance on Martian terrain

10

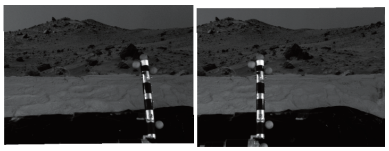
Autonomous D-H Parameter Determination for a Damaged Manipulator Using Stereo Cameras

R. A. Fallows, D. P. Barnes and S. M. Pugh
Space Robotics Research Group, Department of Computer Science, Aberystwyth University

- Denavit-Hartenberg parameters for a manipulator can be calculated via simple rotation of a link about it's joint.
- Accurate measurement of the position of the end-point of the link is required.
- In a planetary mission, this could be achieved using stereo cameras.
- It is found that an accurate calibration is possible.
- However, very small errors in the end-point measurement position may result in calibration errors above acceptable bounds.



The deformable arm and stereo cameras setup.



Example stereo images.

click to Paper

Poster Session

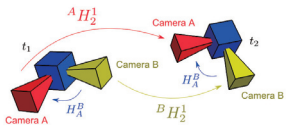
Time 16:00-17:30
Place: Room 204

11

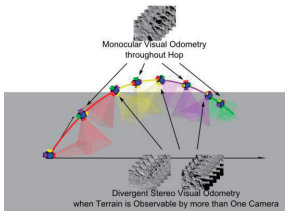
Divergent Stereo Visual Odometry for a Hopping Rover on an Asteroid Surface

Edmond Wai Yan So*, Tetsuo Yoshimitsu**, and Takashi Kubota***
*The Graduate University for Advanced Studies, Japan
**JAXA ISAS, Japan

- Trajectory of a hopping rover on an asteroid surface is estimated using visual odometry.
- Configuration of multiple monocular cameras pointing in different directions is used to continuously track features on ground terrain under continuous rotational motion
- Propagating an initial scale factor obtained using stereo cameras leads to rapid accumulation of error
- Independent estimation of absolute scale factor throughout a hop can mitigate error propagation
- Efficient method is proposed for estimating absolute motion using "*5+1*" point correspondences from multiple cameras without overlapping views



Multiple Cameras without Overlapping Views



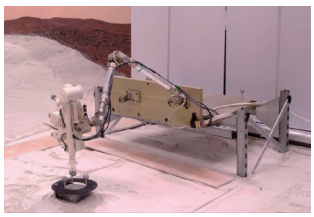
Hopping Visual Odometry using Divergent Stereo

12

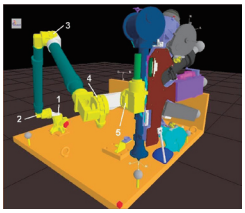
Lightweight Arm Operations for Planetary Sample Return

Laurence Tyler*, Dave Barnes** and Paul McMahon***
*Institute of Maths & Physics, Aberystwyth University, UK
** Dept of Computer Science, Aberystwyth University, UK
***EADS Astrium, Stevenage, UK

- A study of a lightweight arm design for future rover missions
- Beagle 2 arm used as baseline design
- Repeatability and accuracy tested
- New operation modes implemented, including straight-line motion
- Mechanical issues identified and improvements suggested
- Conclusions: Arm design can easily be adapted for a future exploratory/sample return mission. Calibrated arm deflection model required to gain full benefit
- Further arm development ongoing, to be reported later



Test rig with deployed instrument arm



Virtual workcell

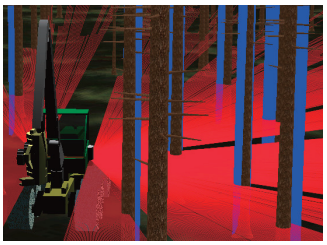
click to Paper

13

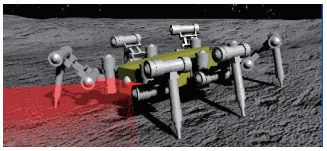
Discussion of a Self-Localization and Navigation Unit for Mobile Robots in Extraterrestrial Environments

J. Rossmann*, C. Schlette*, M. Emde* and B. Sondermann*
*Institute of Man-Machine Interaction, RWTH Aachen University, Germany

- Basis is a general, highly modular concept for self-localization and navigation of mobile platforms
- So far, the concept was successfully implemented to guide mobile platforms in unstructured, earthbound environments
- Now, we are adapting the earthbound implementation to extraterrestrial environments, facing the discussions
  - Selection of sensors depending on environmental conditions and object types
  - Object recognition depending on environmental conditions, object types and sensor types



Well-proven localization in forest environment



Simulation of SCARABEUS rover in our virtual testbed

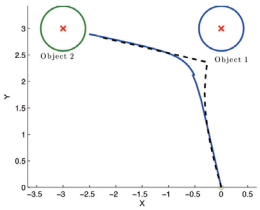
14

Path Planning for Distributed Rover Science

Andrew Klesh
JAXA Space Exploration Center (JSPEC), JAXA, Japan

- Remote sensor dynamics can be modeled using information and estimation theory
- These dynamics should be exploited for trajectory planning, but the TPBVP is difficult to solve in an efficient manner
- Real-time heuristics can be employed to find a solution comparable to optimal paths
- A steepest-gradient heuristic is derived for single and multiple vehicles
- Simulation results and experimental validation on a hardware testbed provided
- The heuristic proves to be computationally tractable and enables new methods for science collection, such as in tomography missions

Time-Lapse Composite of Experimental Results



Comparison of Heuristic (dashed) and Optimal Path (solid)

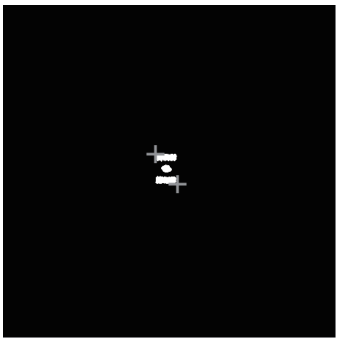
click to Paper

15

Preliminary Study on Optical Utilization of Spacecraft Shadow Images

Naoko Ogawa*
*JAXA Space Exploration Center, JAXA, Japan

- A spacecraft flying over a celestial body sometimes casts its shadow on the ground.
- Since the size and shape of the shadow are known, it can be utilized for guidance and navigation on the natural terrain without artificial landmarks
- We especially focus on the existence of blurred penumbra regions around the shadows
- We discuss preliminary feasibility of measurement of altitude or assistance of human or machine recognition of terrain shapes by using shadows.



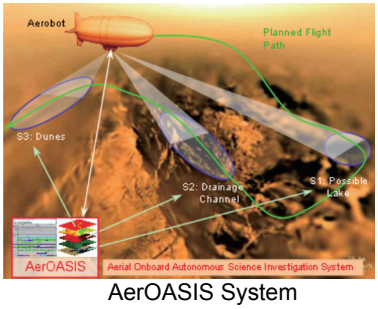
A processed image of a shadow and detected bounding box corners indicating the shadow size.

16

Robust and Opportunistic Autonomous Science for a Potential Titan Aerobot

Daniel Gaines, Tara Estlin, Steve Schaffer and Alberto Elfes*
*Jet Propulsion Laboratory, California Institute of Technology, USA

- Aerboots offer traversal capabilities orders of magnitude greater than rovers.
- Comm. limitations and blackouts result in need for autnomous capabilities to increase science return.
- AerOASIS provides onboard science analysis and planning for robust, opportunistic exploration.
- Prioritize data to maximize available downlink.
- Adjust plan to respond to detected events before opportunity is missed.
- Enables scientists to guide behavior despite remote nature of mission.
- Technology demonstrated on JPL prototype aerobot.



AerOASIS System

Field Trials

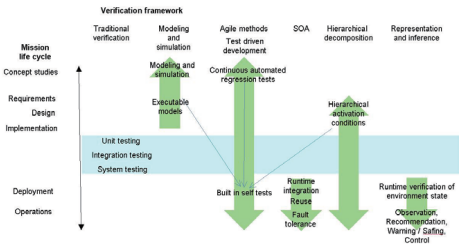
click to Paper

17

Verification of Intelligent Systems Throughout the Software Life Cycle

L.Hartman*
*Space Exploration Directorate, Canadian Space Agency, Canada

- Intelligent systems address challenging requirements and are hard to verify
- We can extend verification earlier and later in the mission life cycle
- Modelling, simulation, executable models, agile methods extend verification to early mission concept studies
- Built in self test, SOA fault tolerance, hierarchical decomposition, representation and inference extend verification to deployment and operations



Verification throughout life cycle

18

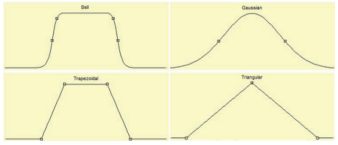
Knowledge based Science Target Identification System (KSTIS)

Stephen Pugh*, Dave Barnes*, Derek Pullan** and Laurence Tyler*

*Computer Science Department, Aberystwyth University
**Department of Physics & Astronomy, University of Leicester

- KSTIS is a Fuzzy knowledge based system.
- It has been designed with the aid of a planetary geologist expert.
- The goal is to effectively categorize the scientific value of the visible features of potential scientific targets, based upon the primary attributes of geological assessment; structure, texture and composition.
- The output of KSTIS is produced in the form of a rank order list of science targets.
- Membership functions and rules have been designed to model the way that the expert's interest in certain features.

Potential science targets identified and labelled



Four types of membership function used

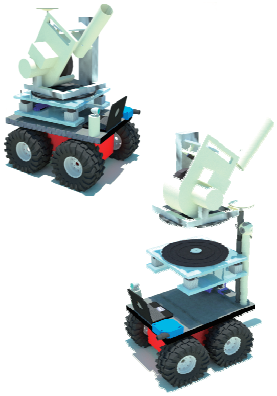
click to Paper

19

i-SAIRAS2010
"Robotic Deployment System For Space Exploration"

D.Sanz, M.Garzon and A.Barrientos*
*Robotics and Cybernetics Group.
Centre for Automation and Robotics (CAR), UPM-CSIC, Spain

- It has been designed and implemented a real robotic system for WSN nodes deployment, within the framework of ESA's WIPE project.
- The main application is planetary exploration missions, where the objetive scenario is Mars surface.
- The system is composed by a rover and a launching system, that increases the deployment range and allows the node placement in unapproachable points.
- It has been physically implemented, tested and validated, obtaining an accuracy of 0.4m in a 30m range.



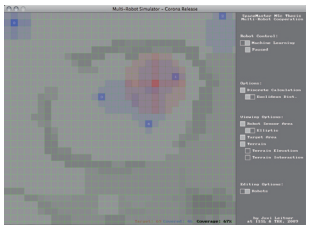
3D Model of the system

20

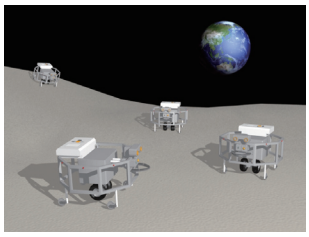
On Cooperation In A Multi Robot Society For Space Exploration

D. Leal Martínez* and J. Leitner**
SpaceMaster Robotics Team
*Aalto University School of Science and Technology
**Advanced Concepts Team, ESA

- Multi robot society built with LEGO Mindstorms and extension board
- SMRTCTRL (Multi-Agent) simulator developed, also used for testing the robots
- Cooperation (vector-based and OCS) as well as reconfiguration (leader selection based) control implemented
- Future: extend cooperation control, robustness and heterogeneous society



SMRTCTRLSimulator



Artist's Impression

SMURFS Presentation

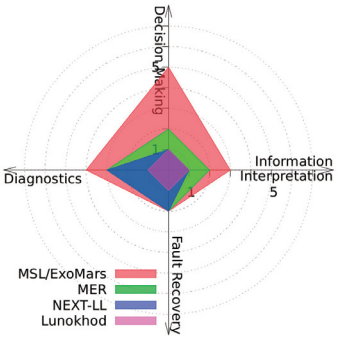
click to Paper

21

Classifying Autonomy for Mobile Space Exploration Robots

Sylvain Joyeux* and Jakob Schwendner*
*Robotics Innovation Center, DFKI, Germany

- Technologies that allow to provide autonomy is critical for future exploration missions
- Classifications schemes are important in the process of designing, evaluating and benchmarking such systems.
- We propose a new scheme for the classification of robotic systems in the domain of space exploration.
- We compare that scheme with existing ones, and apply it to existing and future missions (Left figure)



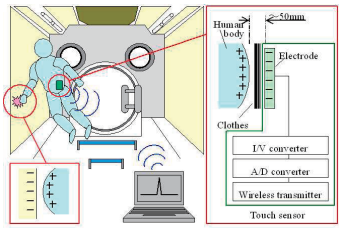
Classification of existing and future missions in the proposed scheme

22

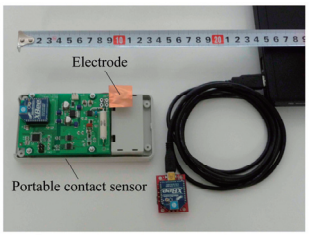
New Approach to Touch Sensing Technique Based on Measurement of Current Generated by Electrostatic Induction

Kurita K
Kochi National College of Technology, Japan

- The conventional touch sensors are use to detect contact between the sensor and an object.
- We propose a new concept for touch sensors based on measurement of **current generated by electrostatic induction**.
- We develop a method to detect contact **in the absence of any direct interaction** between the sensor and the object, the method will find wide application not only on earth but also in space.
- When a human body comes in contact with an object, **electrostatic charge** generated in the human body due to **the tribological interaction**.
- As a result, **an instantaneous change is observed in the electric potential** of the human body.
- The proposed sensor can detect **the timing of contact** between tow objects under perfect noncontact condition.



Schematic of measurement system



Contact detection sensor

click to Paper

23

Multiobjective Optimization Genetic Algorithms for Domestic Airline Crew Pairing Problems

Tung-Kuan Liu*, Chiu-Hung Chen*, Jyh-Horng Chou**, Wen-Hsien Ho** and Shinn-Horng Chen**
* Institute of Engineering Science and Technology, Natl. Kaohsiung First Univ. of Scie. and Tech., Taiwan, R.O.C.
** Department of Medical Information Management, Kaohsiung Medical University, Taiwan, R.O.C.
** Department of Mechanical Engineering, Natl. Kaohsiung Univ. of Applied Sciences, Taiwan, R.O.C.

- Airline crew pairing problems involve assigning the required crew members to each flight segment in a given time period.
- The crew pairing problem considered in this paper contains the following issues:

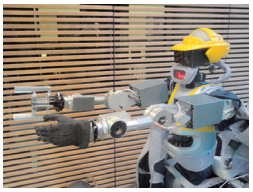
1. Minimizing number of groups.
2. Minimizing layover number.
3. Satisfying the laws and regulations.

24

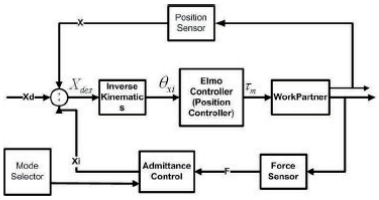
Manipulator Control for Physical Astronaut-Robot Interaction

Melak Zebenay*, Seppo Heikkilä**
*Germany Aerospace Center, DLR, Germany
e-mail: melak.zebenay@dlr.de
**Automation Technology Laboratory, Aalto University, Finland
e-mail: Seppo.Heikkila@tkk.fi

- Brief overview of robot manipulator interaction control algorithms
- Presents compliance control algorithm for *WorkPartner* robot, with three modes of operations (behaviors)
- The modes of operation, targeted for astronaut robot physical interaction, are follow movemen adapt movement and hold positions
- Proposed control algorithm provides an intuitive and seamless way to change between the control behaviors



WorkPartner robot



Proposed control algorithm

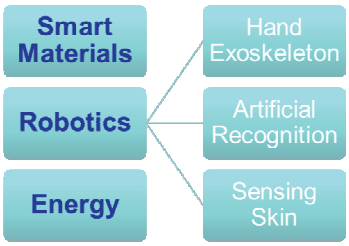
click to Paper

25

Centre for Space Human Robotics of IIT@Polito: a New Italian Initiative

Ferraris S*, Fossati F*, Ambrosio E P**, Manfredi D**, Lombardi L**, Quaglio M** , Bianco S**, Civera P***, Calderale P M***, Pirri C F **,***, Messidoro P*, and Profumo F**,***
*Thales Alenia Space, Italy
**Center for Space Human Robotics – IIT, Italy
***Politecnico di Torino, Italy

- A new research center has been set in Turin, Italy, at the beginning of 2010
- **Mission**: to reach a step further in the study of the future generation of **space humanoid robotics** and to be recognized as a leader laboratory in solutions and selected technologies for humanoid robotics
- **Research Platforms**:



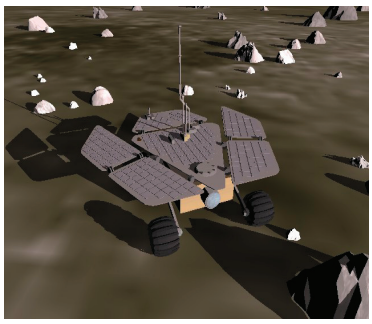
- **Robotics**: development and prototyping of integrated systems for space human robotic application
- **Smart materials**: innovative MEMS and NEMS solutions for micro and nano sensors and actuators for space humanoid applications
- **Energy**: investigating innovative systems for energy production and storage

26

Multi-body techniques to model rover motion on soft terrain

Francesconi P.*, Di Mauro G., Lombardi R., and Lavagna M.*
*Politecnico di Milano, Dipartimento di Ingegneria Aerospaziale, Italy
Email: pfrancesconi@aero.polimi.it

- Tool developed to provide a general purpose testbed to validate the design, to simulate and settle surface operations to check for on-board autonomy performances.
- User defined rover configuration, navigation module (A*, PRM), multi-body model of the chassis, wheel-soil interaction.
- The proposed framework must be able to support multiple representation of the surface geometry, to accept environment assembled from heterogeneous component terrain models, to enable the use of overlays of surface properties such as material composition, texture, albedo, terra-mechanics parameters
- Multi-body dynamics coupled with Bekker theory allows to evaluate actions acting on the rover chassis



click to Paper

back

Digest and paper

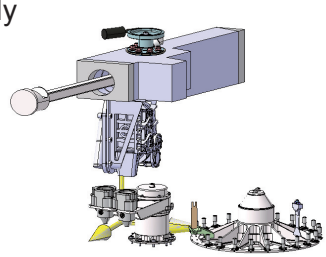
(Wednesday, September 1, 2010)

1

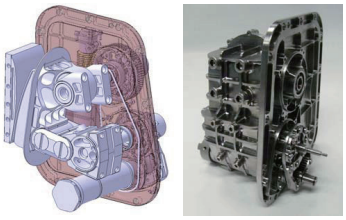
Design and Testing of the ExoMars Sample Preparation and Distribution System

W. Schulte*, T. Viscor, M. Manhart*, P. Hofmann*, E. Re**, P. Baglioni***
*Kayser-Threde GmbH, Germany
**Selex Galileo S.p.A., Italy
***ESA/ESTEC

- The preparation and distribution of Mars rock and soil samples for scientific analysis onboard the ExoMars Rover is an enabling technology in support of future exploration missions
- The complex autonomously operated mechanisms of the ESA ExoMars Sample Preparation and Distribution System (SPDS) are developed by Kayser-Threde GmbH
- Functions: sample transfer, crushing, dosing and distribution of Mars rock powder samples, presentation to science instruments
- Breadboard development and test activities are in progress and well advanced



SPDS Mechanisms



Crushing Station

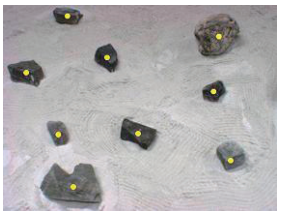
2

Automatic Pointing and Image Capture (APIC) for ExoMars type mission

Stephen Pugh, Laurence Tyler and Dave Barnes

Computer Science Department, Aberystwyth University

- APIC's aim is to increase science data return without removing Earth-based decision points.
- APIC utilises basic operations on-board the rover to identify and locate areas of interest in the scene which are then imaged with the HRC (High Resolution Camera)
- APIC uses only one WAC (Wide Angled Camera) image to calculate the approximate location of each target.
- APIC could be viewed as a precursor to an autonomous exploration system.



Input image annotated with calculated rock centroids.

4 of the 9 HRC images output by APIC

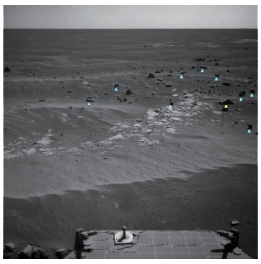
click to Paper

3

AEGIS Automated Targeting for the MER Opportunity Rover

T. Estlin, B. Bornstein, D. Gaines, D. R. Thompson, R. Castaño, R. C. Anderson, C. de Granville, M. Burl, M. Judd, and S. Chien
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

- AEGIS provides automated targeting for the MER Rover Mission
- Enables onboard software to:
  - Analyze images onboard
  - Select new targets based on criteria specified by scientists
  - Automatically acquire new measurements with the MER Panoramic cameras
- Uploaded to Opportunity in December 2009
- Checked out in March 2010 and fully operational
- Directly applicable to the 2011 MSL rover ChemCam spectrometer



Top targets selected in MER Navigation camera image

Resulting MER 13F Panoramic camera image

click to Paper

Session W1B — Multi-Robot Exploration

Time: 9:15-10:30
Place: Room 202

1

Towards a Modular Reconfigurable Heterogeneous Multi-Robot Lunar Exploration System

Florian Cordes*, Daniel Bindel**, Caroline Lange***, Frank Kirchner*
*DFKI Robotics Innovation Center, Bremen, Germany
**ZARM Center of Applied Space Technology and Microgravity, Bremen, Germany
***DLR – Institute of Space Systems, Bremen, Germany

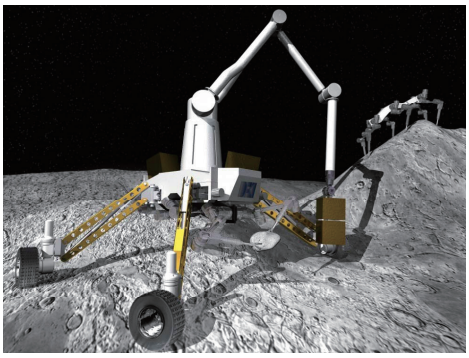


Figure 1 – Artist impression of RIMRES system: Rover deploying payload, while scout is docked beneath. Background: Scout climbs steep slope

- Project RIMRES is presented
- RIMRES develops a heterogeneous robotic system for crater exploration
- Wheeled rover and legged scout cooperate to benefit from their respective capabilities
- Uniform mechatronic interface to provide mechanical, and electrical connections between mobile and immobile units of the system
- Dynamic software framework for facilitating the operations of the modular overall system

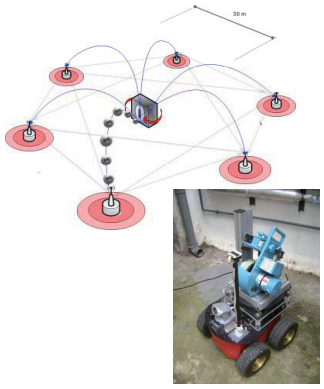
2

Wireless sensor web for rover planetary exploration

A.Medina*, C.Negueruela*, L.Mollinedo*, F.Gandía*,
A.Barrientos**, C.Rossi**, D. Sanz**, A. Puiatti***, M.Mura***, D.Puccinelli***
J.F.Dufour****

*Advanced Space Systems and Technologies, GMV
** Centre for Automation and Robotics (CAR), UPM-CSIC
*** Scuola Universitaria Professionale della Svizzera italiana (SUPSI)
***** TEC-EDD, ESA

- This study **RF-WIPE** (RF Wireless for Planetary Exploration) is an **European Space Agency** (ESA) project.
- Industrial consortium lead by GMV subcontracting:
  - SUPSI (University of Applied Sciences and Arts of Southern Switzerland)
  - UPM (Technical University of Madrid)
- Identification of planetary exploration scenarios for WSN's 802.15.4 (wireless sensors networks).



Networked planetary exploration mission using a rover as mobile sink node

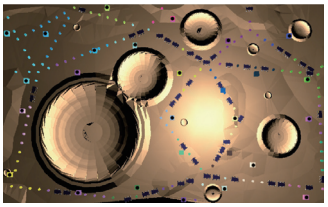
click to Paper

3

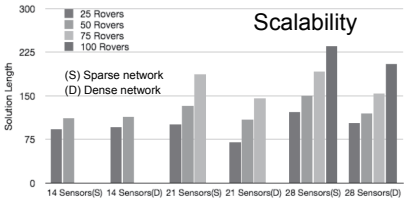
Network-Guided Multi-Robot Path Planning For Resource-Constrained Planetary Rovers

Ryan Luna, Alexis Oyama, Kostas E. Bekris
Computer Science and Engineering Department
University of Nevada, Reno – Reno, NV, USA

- *Premise*: Use a network to coordinate the paths of multiple rovers along a predefined roadmap
- *Approach*: Online, distributed, message-passing solution, where nodes have only local information.
  - Nodes compute alternative routes for robots
  - Path assignment achieved through coordination
  - Formulation: Distributed Constraint Optimization
- *Simulated experiments*:
  - Solutions computed on the fly (500ms/step)
  - Collisions are avoided
  - Deadlocks are rare up to many tens of rovers
  - Good quality path until a saturation point



Simulation snapshot: Multiple robots guided by network nodes along a roadmap



click to Paper

Session W1C Rover Modeling and Simulation

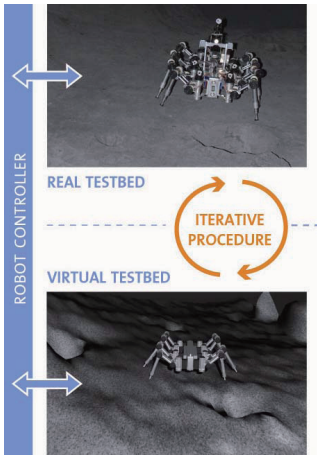
Time: 9:15-10:30
Place: Room 206

1

Developing a Virtual Environment for Extraterrestrial Legged Robot with Focus on Lunar Crater Exploration

Yong-Ho Yoo*, Thomas Jung**, Malte Roemmermann*, Malte Rast**, Frank Kirchner*, Juergen Rossmann**
*Robotics Innovation Center, DFKI Bremen, Germany
**Institute of Man-Machine Interaction, RWTH Aachen University, Germany

- In the project Virtual Crater, we develop a real-time capable virtual lunar testbed, that makes it possible to program and test missions of lunar surface exploration and to demonstrate new development concepts.
- This paper presents the project goals and current approaches. An effective tool-chain to optimize system parameters by precisely modeling and simulating the given lunar scenarios close to real time is proposed. Emphasis has been laid on real-time capabilities to intuitively support the system construction and on elaborate soil contact models and the identification of the respective parameters of regolith. Using the proposed tool-chain, the high-fidelity simulation of a legged robot and the leg-soil contact are achieved.

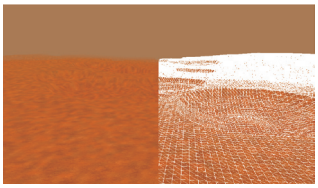


2

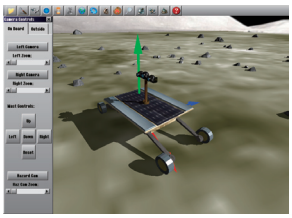
3D Virtual Platform to Validate Planetary Vehicles Design and Operations

Riccardo Lombardi, Pietro Francesconi*, Michèle R. Lavagna*
*Dipartimento Ingegneria Aerospaziale, DIA, Politecnico di Milano, Italia

- The paper presents the state of the art of the 3D virtual simulator currently under development by the DIA.
- The simulation tool includes user-defined environments (Surface, Atmosphere and Orbital Mechanics) and robots (Landers and Rovers).
- The 3D visualization allows to create the input for virtual cameras, base point for the navigation process.
- The embedded physics engine evaluates real time robot-environment interactions.
- Models of the vehicle subsystems and functionality at various level of detail can be inserted and tested.



Martian Landing



Lunar Rover

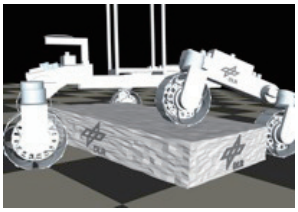
click to Paper

3

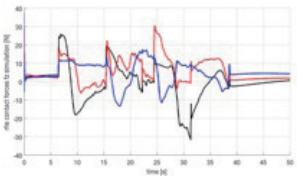
Multi-Body System and Contact Simulation within the Design Development of Planetary Surface Exploration Systems

A. Gibbesch*, R. Krenn*, F. Herrmann*, B. Schäfer*, B. Rebele*, E. Allouis** and T. Diedrich***
*DLR - German Aerospace Center, Institute of Robotics and Mechatronics, Weßling, Germany
**EADS Astrium Ltd, Stevenage, UK
***EADS Astrium GmbH, Bremen, Germany

- MBS simulation in combination with sophisticated contact simulation methods are presented
- contact calculations for soft and hard contact bodies are conducted for almost arbitrarily shaped surfaces
- three different space applications are presented: ExoMars BB2 rover, MoonNext rover, MASCOT hopping mechanism
- correlations with measurement results are shown for the ExoMars rover
- design evaluations are presented for the MoonNext rover and the MASCOT hopping mechanism



ExoMars rover MBS simulation



rover contact force simulation

click to Paper

Session W2A

Drilling System

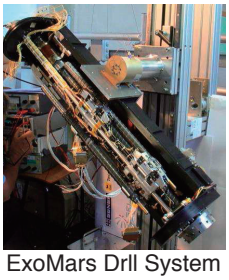
Time: 10:35-11:50
Place: Room 201

1

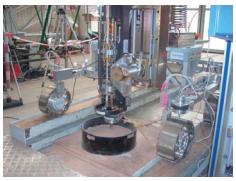
The Drill and Sampling System for the ExoMars Rover

Piergiovanni Magnani*, Edoardo Re*, Samuel Senese*, Francesco Rizzi*
Alessandro Gily**, Pietro Baglioni***
*Selex Galileo, Space L.o.B, Italy
**Thales Alenia Space, Torino, Italy
***ESA/ESTEC, The Netherland

- The ExoMars Rover will install a Drill and Sampling system to perform the collection and distribution to on board instrumentation of subsurface samples collected at depths down to two meters
- Several parts and a complete Drill and Sampling System has been developed and tested in a variety of conditions
- Verifications performed include: several tens of samplings, verifications in Mars like conditions, ten full automatic drillings at two meters (also integrated with the Rover BB)
- Further verifications are now planned including issues related to drilling capability in presence of water/ice
- The gained information certainly allow to enter phase C/D with a mature design an high degree of confidence.



ExoMars Drll System



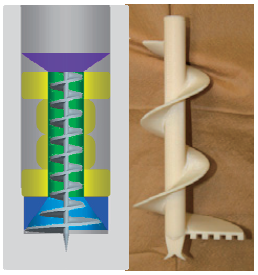
Drill BB on Rover BB

2

An Earth Auger as Excavator for Planetary Underground Explorer Robot Using Peristaltic Crawling

H. Omori *, T. Murakami*, H. Nagai *, T. Nakamura *, and T. Kubota * *
*Department of Precision Mechanics, Chuo University, Japan
**Japan Aerospace Exploration Agency (JAXA)

- We propose a planetary underground explorer using peristaltic crawling as a propulsion part and an earth auger as an excavation part
- Two different diameter earth augers are developed to equip with the propulsion part
- Auger head diameter is 130 [mm] and the transport diameter is 65 [mm]
- Excavation experiments of pushing force and rotation speed are conducted
- Both developed earth auger could excavate 180 [mm] in depth



Underground explorer and developed earth auger

Excavation experiments

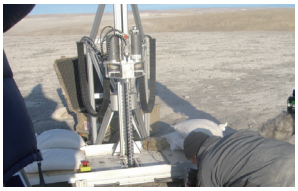
click to Paper

3

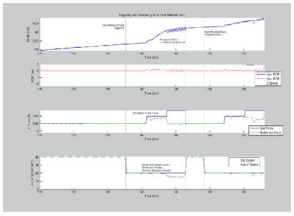
Robotic Planetary Drill Tests

B. J. Glass*, S. Thompson*, G. Paulsen**
*Computational Sciences Division, NASA Ames Research Center, USA
**Honeybee Robotics, New York, NY, USA

- Subsurface access requires drilling (ices, organics, life detection)
- Lightspeed time-delays make teleoperation infeasible for drilling beyond the Moon
- Low power, blind drilling, light weights on bit make drilling difficult
- NASA projects (MARTE, DAME) have developed and tested robotic topside sample handling and downhole drill diagnostics and controls
- Diagnostics: heuristics, vibration monitoring/neural -net, model-based; voting scheme
- Ported in 2009 to CRUX rotary-percussive drill and field-tested successfully in Arctic crater
- Future direction: flight avionics, software



CRUX Drill Test at Haughton Crater



Ice Lens Detection and Response

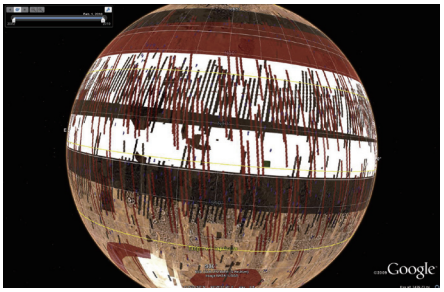
click to Paper

1

A Tool for Scheduling THEMIS Observations

G. Rabideau* , S. Chien*, D. Mclaren*, R. Knight*,
S. Anwar**, G. Mehall**, P. Christensen**
*Jet Propulsion Laboratory, California Institute of Technology, USA
**School of Earth and Space Exploration, Arizona State University, USA

- The THEMIS Observation Scheduling Tool (TOST) has been developed that generates candidate THEMIS observations plans
- TOST incorporates priorities of both targeted and mapping campaigns
- TOST incorporates a range of spacecraft constraints including observation spacing, length, onboard storage, command buffer, and others.
- TOST is currently under evaluation by the THEMIS team at ASU.



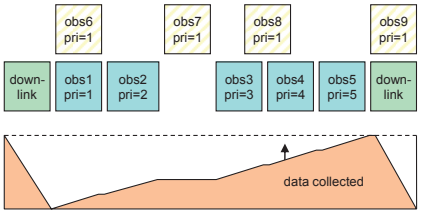
THEMIS observation plan highlighting observations for subsolar region campaign

2

Goal Selection for Embedded Systems with Oversubscribed Resources

Gregg Rabideau, Steve Chien, David McLaren
Artificial Intelligence Group, JPL, USA

- Flexible and Robust On-Board Goals and Sequences for Science
  - Independent, “last minute”, goal submission
  - Autonomous goal selection and optimization
- Supports:
  - Changing science needs
  - On-board science processing, event detection and response
  - Ground-based sensorweb response
  - Unexpected goal interactions



Selecting Observation Goals

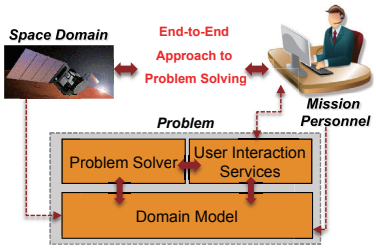
click to Paper

3

Deploying Interactive Mission Planning Tools Experiences and Lessons Learned

A. Cesta, G. Cortellessa, S. Fratini, A. Oddi and G. Bernardi
Institute of Cognitive Science and Technology – ISTC-CNR, Rome, Italy

- **Context**: support Mission Planning at ESA Ground Segment
- **Driving mission**: ***Mars Express***
- **Operational prototypes:** Mexar, Mexar2, Raxem, Raxem2, MrSPOCK (*all in continuous use at ESA-ESOC*)
- **Enabling software platform:** APSI framework (general framework to support application development for planning and scheduling in future missions)
- **Lessons learned:** modeling approach (*timeline-based*); algorithm support (*multi-objectives formulation, heuristics*); end to-end development approach (*user in the loop*); interactive services (*solution quality*, *what-if analysis*, *incremental refinement/interaction support*)



Key "ingredients" to support interactive mission planning

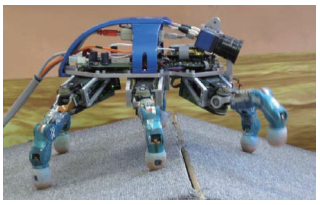
click to Paper

1

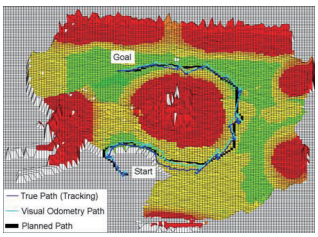
Towards an Autonomous Walking Robot for Planetary Surfaces

Martin Görner*, Annett Chilian*, and Heiko Hirschmüller*
*DLR German Aerospace Center, Institute of Robotics and Mechatronics, Germany

- DLR Crawler: six-legged actively compliant robot
- Various compliance control algorithms possible
- Tripod gait for moderate terrain and biologically inspired gait for challenging terrain
- Stretch, search and elevation reflexes for reactively crossing obstacles within the walking height
- Stereo camera based navigation layer creates a map and estimates terrain traversabiltiy
- Paths are planned taking the terrain traversability into account
- Motion commands are sent to the walking layer and gaits can be switched according to terrain difficulty



DRL Crawler



Navigation Map

2

Study on Efficient Attitude of a Multi-Legged Planetary Rover with Isotropic Leg Arrangement

Shinji Nishikori*, Shinji Hokamoto*, and Takashi Kubota**
*Dept. of Aeronautics & Astronautics, Kyushu Univ., Japan
**Spacecraft Engineering Division, ISAS/JAXA, Japan

- This study deals with an 8-legged rover with spherically isotropic leg arrangement shown in Fig.1.
- The proposed rover can keep mobility even when it overturns.
- The proposed rover can walk with various attitudes, although its 8 legs can cause higher energy consumption.
- Adequate walking attitudes are proposed from the view point of energy efficiency (attitudes (b) and (c) in Fig.2).
- Reasonable link-lengths for the proposed attitudes are investigated.

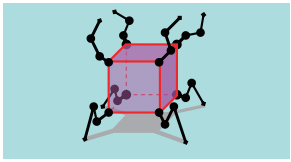


Fig.1 Overview of the rover in this study

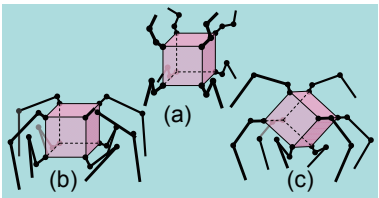


Fig.2 Three candidates for walking attitude

click to Paper

3

Effects of Wheel Synchronization for the Hybrid Leg-Wheel Robot Asguard

Ajish Babu, Sylvain Joyeux, Jakob Schwendner, and Felix Grimminger
German Research Center for Artificial Intelligence (DFKI),
Robotics Innovation Center, Bremen, Germany

- ASGUARD - robot with a new hybrid leg-wheel, designed to traverse unstructured terrain
- This paper studies the effect of synchronization of wheels on locomotion.
- Locomotion is evaluated by the smoothness of motion known as ***Specific Resistance***
- Analyzes effects of front-back and left-right wheel offsets
- Offsets influence efficiency, especially at low speeds
- Proper synchronization exchanges the energy within the robot, minimizing losses

ASGUARD Robot

ASGUARD wheel

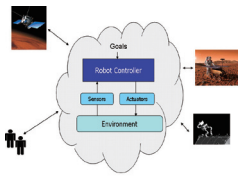
click to Paper

1

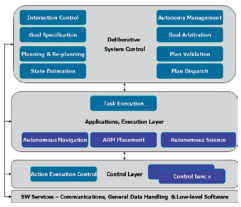
High-level Autonomy for Exploration Robotics

M. Woods*, A. Shaw*, R. Aylett,**, A. Gily***, F. Didot****
* SciSys, UK,
**Heriot-Watt University, Scotland
*** Thales-Alenia Space Italia,Italy
****ESA/ESTEC, The Netherlands

- Exploration Robotics (XROB) study for ESA
- Investigating the definition of robotic autonomy components across all phases of missions to Mars, the Moon and In-Orbit.
- This paper looks at the specification of generic, high-level autonomy components
- List of components identified
- Assessment of how best to implement the components (i.e. what level of human intervention required) carried out
- Components assigned an appropriate autonomy level according to mission and phase



Goal Orientated Autonomy



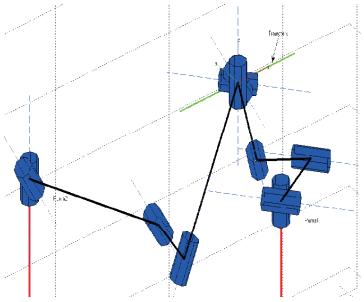
Component Lists

2

Fault Tolerance Operation of Cooperative Manipulators

Hamid Abdi*, Saeid Nahavandi**, Zoran Najdovski***
*,**,*** Centre for Intelligent Systems Research, Deakin University,
Waurn Ponds, VIC 3217, Australia
e-mail: hamid.abdi@deakin.edu.au

- Autonomous or teleoperation of critical tasks in space applications require fault tolerant robotic manipulators.
- It is presumed that the manipulator is fault tolerant on its trajectory then the fault tolerant force is studied.
- Cooperative fault tolerant force is addressed.
- The cooperative manipulators are used to compensate a force jump due to a joint failure of a manipulator.
- Three collaboration strategies are proposed.
- Optimality condition of each strategy is presented.
- The strategies are validated via a fault tolerant force under a joint failure scenario by two PUMA560 models .



Simulation of 2 manipulators Applying a force on a desired trajectory

click to Paper

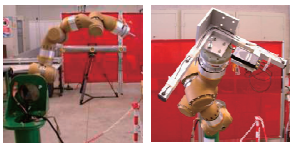
3

DEXARM Integration and Test Results

A. Rusconi*, P. Magnani*, A. Della Pietà**, P. Campo***,
G. Magnani****, G. Visentin*****
*SELEX Galileo, Italy, **Tecnomare, Italy
***SENER Ingeniería y Sistemas S.A., Spain
****Politecnico di Milano, Italy
*****ESA/ESTEC, The Netherlands

- DEXARM (Dextrous Robot Arm):
  - Robot arm comparable in size, force and dexterity to a human arm
  - Prepare the technology for future missions
- Key aspects:
  - Dextrous kinematics configuration and high performance
  - Minimization of resources and high integration, preserving modularity
- This paper describes engineering model integration and test:
  - Two main incremental steps: single joint and complete arm
  - Results are discussed, in relation to design choices (covering mechanical and electrical design, sensors, actuators and control)

DEXARM



ISO-9283 test set-up

click to Paper

Session W3B ISS and Human Operations

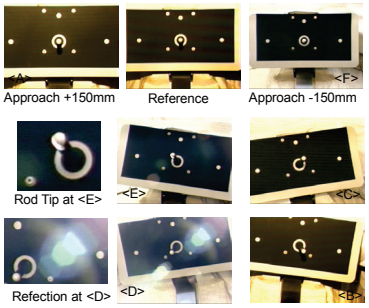
Time: 14:00-16:05
Place: Room 202

1

JEMRMS Initial Checkout and Payload Berthing

Hiroshi Ueno, Shinobu Doi and Hitoshi Morimoto
*Human Space Systems and Utilization Mission Directorate, JAXA, Japan

- The JEM (Japanese Experimental Module) Remote Manipulator System (JEMRMS) was launched and deployed on International Space Station (ISS) on June 2008.
- The JEMRMS on-board characteristics has been evaluated at the initial checkout. The JEMRMS wrist camera calibration has been performed to estimate the berthing port location precisely (upper figure).
- On July 2009, JEMRMS successfully transferred and berthed three payloads to Exposed Facility on JEM(lower figure). On September 2009, JEMRMS performed to install the Exposed Pallet (EP) to EF in addition to berthing two payloads.
- The lessons learned from JEMRMS berthing operation are presented.



15mm[Y,Z], 8deg[Pitch, Yaw, Roll]
JEMRMS Camera Calibration

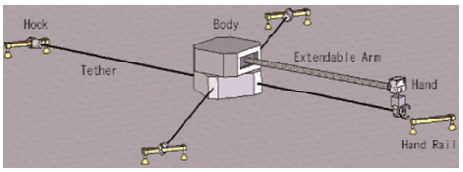
Payload Berthing Operation

2

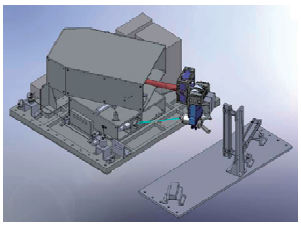
Vibration Control of Flexible Arm for Robot Experiment on JEM

Daichi Hirano*, Hiroki Nakanishi*, Kazuya Yoshida*,
Mitsushige Oda**, Taihei Ueno**, and Takeshi Kuratomi***
*Department of Aerospace Engineering, Tohoku University, Japan
**Space Robotics Research Group, JAXA, Japan
***WEL RESEARCH Co., Ltd, Japan

- Tether based locomotion robot to support the tasks performed by astronaut is introduced.
- Robot experiment on International Space Station called REXJ is described.
- Dynamic model of the extendable arm used in REXJ is identified.
- Vibration suppress control strategy for the extendable arm is derived.
- The efficiency of the vibration suppress control is verified with numerical simulation.



Tether based locomotion robot



REXJ mission

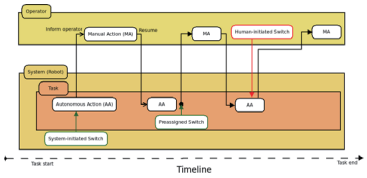
click to Paper

3

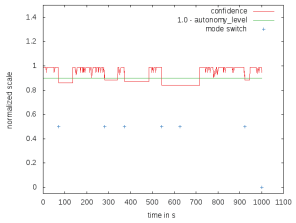
Using a self-confidence measure for a system-initiated switch between autonomy modes

Thomas M. Roehr*, Yuping Shi*
*DFKI Bremen – Robotics Innovation Center, Bremen, Germany

- The project RIMRES develops a reconfigurable multi-robot team for deployment on the lunar surface
- Efficient control for the mixed human-robot team is required, using three autonomy modes:
  - manual, mixed-initiative, (fully) autonomous
- We developed a concept for a system-initiated mode switch, using on a formalized trust relationship between humans and robots:
  - comparing trust against the system's current self-confidence triggers the switch to manual mode
- Simulation has been used to produce preliminary results and to illustrate the concept



Initiative of mode switches



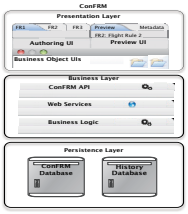
Confidence based switching

4

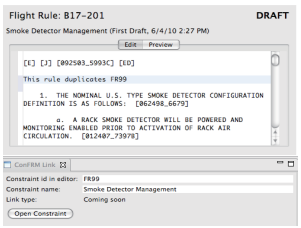
Constraint and Flight Rule Management for Space Mission Operations

J. Barreiro*, J. Chachere*, J. Frank**, C. Bertels*** and A. Crocker***
*SGT, Inc. NASA Ames Research Center Moffett Field, CA, USA
**NASA Ames Research Center Moffett Field, CA, USA
***NASA Johnson Space Center, Houston, TX, USA

- Creation of human spaceflight operations constraints:
  - Constraints share content and refer to each other; trace heritage to other documents and data
- Management of constraints today:
  - Constraints created and enforced by many people, often over years
  - Documented for people and used to configure tools; use of disparate tools duplicates work, creates opportunities for error
- Constraint and Flight Rule Management (ConFRM):
  - Capture knowledge in one place with a convenient UI, and automatically create 'end-use' products, be they documents or tool configurations.



ConFRM software architecture



ConFRM content and link editors

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5

Spatial Planning for International Space Station Crew Operations

Bradley J. Clement*, Javier Barreiro**,
Michael J. Iatauro**, Russell L. Knight*, Jeremy D. Frank**

*Artificial Intelligence Group, Jet Propulsion Laboratory,
California Institute of Technology, USA
e-mail: firstname.lastname@jpl.nasa.gov
**Planning and Scheduling Group, NASA Ames Research Center, USA
e-mail: javier.barreiro@nasa.gov, michael.j.iatauro@nasa.gov, jeremy.d.frank@nasa.gov

click to Paper

Session W3C

Rover Field Test

Time: 14:00-16:05
Place: Room 206

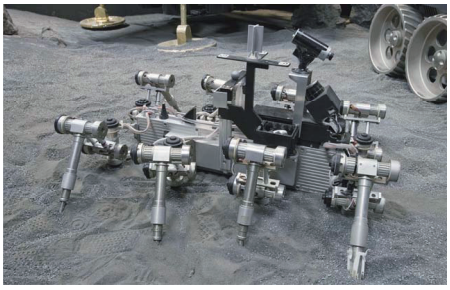
1

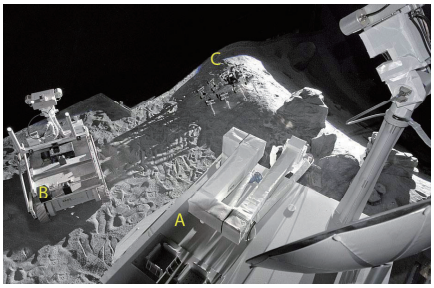
Performance Evaluation of an Heterogeneous Multi-Robot System for Lunar Crater Exploration

Sebastian Bartsch, Florian Cordes,
Stefan Haase, Steffen Planthaber, Thomas M. Röhr

DFKI Robotics Innovation Center, Bremen, Germany

- Evaluation of multi-robot system
- Wheeled rover and legged scout co-operate in artificial lunar crater environment
- Experiments and results for evaluation of parts of the demonstration mission are presented
- Sample pick-up by legged scout
- Climbing steep crater slopes with legged scout
- Autonomous docking procedures between legged scout, wheeled rover and landing unit



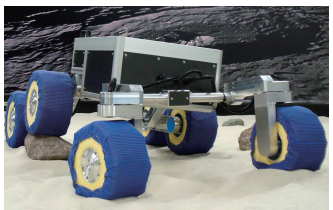


2

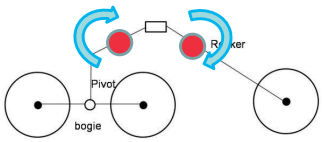
The Evaluation of Planetary Rover for Rough Terrain

Takamasa Naiki*, Takashi Kubota**
*The University of Tokyo, Japan
**Japan Aerospace Exploration Agency, Japan

- In planetary missions, rovers that can traverse over rough terrain are required in order to explore craters and slopes which have high scientific value.
- The common locomotion mechanism of planetary rover is the wheel, because it has high energy efficiency and simplicity. However, a rover which uses the wheel mechanism suffers from its poor traversability.
- To solve this problem, the authors propose a new mobility system with active suspension, which has 12 motors (for drive 6,front wheel steer 2, active suspension 4) and high efficiency and high traversability.
- This paper shows through simulations the effectiveness of the proposed mobility system in its ability to climb slopes and its stability from tip over when traversing various rough terrain using active suspension.



The proposed rover



The locomotive system

click to Paper

3

The Avatar EXPLORE Experiments: Results and Lessons Learned

Erick Dupuis, Pierre Langlois, Jean-Luc Bedwani, David Gingras, Marc Gendron, Alessio Salerno, Pierre Allard, Sébastien Gemme, Régent L'Archevêque, Tom Lamarche
Canadian Space Agency

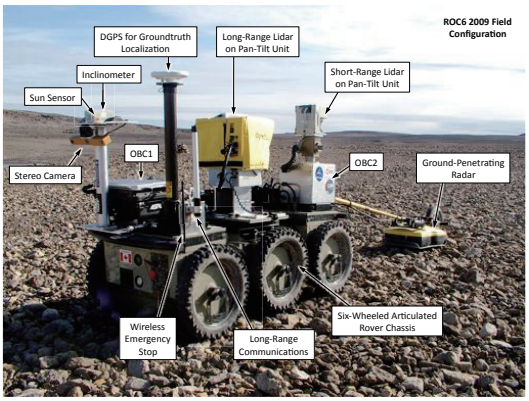
- Demonstrated for the first time ever the control of an exploration rover from space.
- Information-centric concept of operation that abstracts robot from operator
- Off-line operations planning and asynchronous file transfers
- Successfully conducted three experiment series
- Lessons Learned
  - •Operations Concept
  - •Operator Interface
  - •Rover Software
  - •Project Management

4

Field Testing of a Rover GN&C Architecture to Support a Ground-Ice Prospecting Mission to Mars

T Barfoot[a],P Furgale[a],B Stenning[a],P Carle[a],L Thomson[b],G Osinski[b],M Daly[c],N Ghafoor[d]
[a]University of Toronto Institute for Aerospace Studies,
[b]University of Western Ontario, Depts. of Earth Science, Physics and Astronomy,
[c]York University, [d]MDA Space Missions

- Investigation of a ground-ice prospecting mission as a follow-on to Phoenix Mars lander
- Science Instruments: lidar, ground -penetrating radar, stereo camera
- End-to-end mission simulation using a real field robot on real polygonal terrain on Devon Island in the Canadian High Arctic
- Mission concept is possible using existing rover guidance, navigation, and control technologies



Field Robot on Devon Island, Nunavut, Canada

click to Paper

5

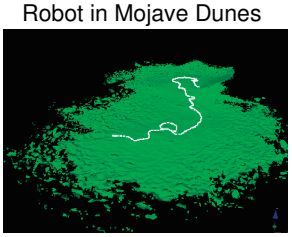
Planetary Rover Visual Motion Estimation improvement for Autonomous, Intelligent, and Robust GN&C

J. Nsasi Bakambu *, C. Langley *, G. Pushpanathan *, W. James MacLean *, R. Mukherji *, E. Dupuis **

* Space Missions, MDA Corporation, Brampton, Ontario, Canada
** Space Exploration, Canadian Space Agency, St-Hubert, Quebec, Canada

- ❑ Improved VME through optimal use of different features from stereo-pair images as visual landmarks.
- ❑ Investigated the use of a long-range and wide FOV 3D sensor to enable VME observability, and thus improve its accuracy.
- ❑ Prior work in this field has focused on VME as an open-loop observer, for providing accurate a posteriori localization when a destination is reached. Our novel approach used the improved VME as feedback for closing the path tracking loop.
- ❑ CORTEX-based supervisory control was effective for monitoring and executing traverses, which resulted in a noticeable increase in the autonomy of the testbed.
- ❑AIR-GNC, which includes terrain scanning, modeling and traversability assessment, and path planning and tracking, has been tested to a high level of maturity.

Robot in Mojave Dunes



Reconstructed Dunes D.E.M

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