Autonomous Robotic Reconnaissance Missions in Extreme Space Environments

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Thank you!!!
Acknowledgements

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Funding Support:
DOD, DOE, NASA, NSF, Bausch & Lomb
Motivation
Planetary Bodies of High Interest

[Images Courtesy NASA]

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OSIRIS-REx: Asteroid Sample Return Mission 2016
Global Scale:

Vast Canyon Systems such as Valles Marineris

Image credit: T. Hare, USGS
Global to Regional Scale:
Central Valles Marineris

Image credit: T. Hare, USGS
Regional to Local Scale:

Ophir Chasma

Ophir Chasma terrain image courtesy ESA/DLR/FU Berlin (G. Neukum)
Example of Recent/Transient Events:
Dark Slope Streaks

[Images courtesy of NASA/JPL/MSSS]
Example of Recent/Transient Events:

Light-toned Gully Deposit

[Images courtesy of NASA/JPL/MSSS]
Example of Recent/Transient Events:

New Impact Crater (also: Volcanoes, Fires, Floods)

[Images courtesy of NASA/JPL/MSSS]
Tier-Scalable Reconnaissance & Autonomous Robotic (Space) Exploration
Traditional Mission Architectures

- **Mars Reconnaissance Orbiter** (courtesy of NASA)
- **Phoenix Lander Mission** (courtesy of NASA)
- **Mars Science Laboratory Rover Mission** (courtesy of NASA)
Tier-Scalable Reconnaissance: Autonomous C⁴ISR Architecture

Fink et al., PSS 2005
Raytheon
Future C⁴ISR Architecture (TSAT)
Financial Disclosure:
Existing Caltech Intellectual Property (IP)

Patent number: US 6,990,406
Title: “MULTI-AGENT AUTONOMOUS SYSTEM”
Authors: Wolfgang Fink et al.

Patent number: US 7,734,063
Title: “MULTI-AGENT AUTONOMOUS SYSTEM”
Authors: Wolfgang Fink et al.

Patent number: US 7,742,845
Title: “MULTI-AGENT AUTONOMOUS SYSTEM AND METHOD”
Authors: Wolfgang Fink et al.
Tier-Scalable Reconnaissance Paradigm and Robotic Test Bed
Featured in SCIENCE 30 July 2010 Vol 329

NEWSFOCUS

Making Smarter, Savvier Robots

The researchers got their meteorite. But the near miss—and the frustrating delay—underscored a defect of current exploration technology. Basically, robots are pretty dumb. Some scientists around the world are striving to change that by developing intelligent robots that can circumvent danger and spot enticing features on their own.

Hundreds of scientists, mostly at NASA and at universities, are working on improving robot explorers. But only a dozen specialize in developing autonomous space systems to give robots freedom to change plans on the fly. The major challenge is to have robots do something more than execute preprogrammed instructions.

On 18 July 2009, the Mars rover Opportunity was scouting toward a distant martian crater when it stopped to examine the ripples of red soil: a bruise-colored rock the size of a watermelon. It looked like a meteorite—potentially evidence that the ancient atmosphere of Mars, like today’s, was thin enough for such rocks to pass through without exploding.

The strange rock was exactly the kind of thing NASA Sensorweb, a group of half a dozen NASA satellites that monitor Earth’s atmosphere. Some scan large sections of Earth’s surface and check out potential volcanic or earthquake hazards in real time, others watch for changes in major impact craters. Rendezvous missions with comets or asteroids and landings on distant moons would also benefit from the autonomous robots, researchers say. On Saturn’s moon Titan, radio waves carrying scientists’ instructions take 90 minutes to travel to the planet and return.

Even more ambitiously, Fink is developing systems to give robots freedom to change their logical architecture—essentially to “rewire” their brains. A robot might make a rule more complicated or simpler by adding or cutting steps, or combining the binary code of two rules and trying out their “off:” If the new rules work well, it adds them to its problem-solving repertoire.

Sensornet is a group of half a dozen NASA satellites that monitor Earth’s atmosphere. Some scan large sections of Earth’s surface and check out potential volcanic or earthquake hazards in real time, others watch for changes in major impact craters. Rendezvous missions with comets or asteroids and landings on distant moons would also benefit from the autonomous robots, researchers say. On Saturn’s moon Titan, radio waves carrying scientists’ instructions take 90 minutes to travel to the planet and return.

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Public Exposure, Media Releases, and Awards

received

NASA Board Award

November 2009
Example of Space-Ground Collaboration:
Locating MER Opportunity (NASA MRO)
Advantages of Tier-scalable Reconnaissance Architecture:

• Overhead navigation affords deployment of less smart, therefore less costly, expendable ground agents
• Deploy *multiple expendable ground agents* in target zones – reduced driving requirement
• Mission *safety* and *redundancy*
• Optimized target identification and obstacle avoidance
• Efficient (overhead) commanding of multiple ground agents

Example (onboard) Instruments/Sensors:

• Optical, IR, UV cameras
• Hyperspectral cameras
• Sonar-systems
• Ground penetrating radar (GPR)
• MEMS-based devices and sensors

Application Examples:

• Operations in hazardous environments (incl. military, biochemical, radiation, or natural disasters)
• Reconnaissance operations (incl. planetary, military, civilian)
• Surveillance operations (e.g., Homeland Security), Stand-off Detection (IEDs)
Tier-Scalable Reconnaissance Robotic Test Bed
Tier-Scalable Reconnaissance Mission Test Bed: Proof-of-Concept Multi-Rover Test Bed

Capabilities:
- Near real-time remote control worldwide
- Autonomous self-commanding
- Autonomous tele-commanding as part of Tier-scalable Reconnaissance® mission architectures
- Capable of complex and numerically intensive onboard calculations
- Hot-swapping of new exploration algorithms while en route
- Emulating realistic space mission communication scenarios
- Cooperative multi-rover operations
- Distributed scientific exploration

Specifications:
- Battery operated
- 4 WD drive
- User-controllable onboard cameras
- Wireless video link (TCP/IP)
- Swappable sensor platform
- Dual core general purpose onboard Unix workstation
- Remote controllable
- TCP/IP enabled (wireless LAN)

~3 kg payload!

Fink & Tarbell, LPSC 2008
Rover “CYCLOPS” featured in Popular Science 2010 and on National Science Foundation 2009 main webpage

CYCLOPS
A Legally Blind Robotic Guinea Pig for Testing Artificial Eyes

Cyclops
Most vision implants are still too crude to test on humans.

On The Job By
Caltech Scientists Create Robot Surrogate for Blind Persons in Testing Visual Prostheses

October 19, 2009

Scientists at the California Institute of Technology have created a remote-controlled robot that is able to simulate the “visual” experience of a blind person who has been implanted with a visual prosthesis, such as an artificial retina. An artificial retina consists of a silicon chip studded with a varying number of electrodes that directly stimulate retinal nerve cells. It is hoped that this approach may one day give blind persons the freedom of independent mobility. Full Story
Tier-Scalable Reconnaissance Mission Test Bed: 
Surface Explorers: Rovers

Rovers:
• Electric motors
• Metal chassis and sensor platform
• General-purpose, high-performance Unix workstation
• Range up to 10 km on one battery charge
• Up to 10 hours onboard computing
• Wireless Internet capability
• > 30 kg payload sustained
• Onboard GPS
• Onboard HD camera

Fink et al., IEEE Aerospace 2011
Catamaran design
• Very stable
• 1.8 m long by 1.5 m wide by 0.5 m tall
• Mass: ~45 kg without sensor payload
• > 68 kg payload capability
• Highly modular design

• Electric motors
• Air-based propulsion system
• General-purpose, high-performance Unix workstation
• Onboard HD cameras
• Onboard side-scanning sonar
• Wireless Internet capability (Earth applications)
• Onboard GPS (Earth applications)

Fink et al., IEEE Aerospace 2012
Robotic Lake Lander/Sea-Rover Test Bed:
The REAL Thing

Fink et al., IEEE Aerospace 2012
World-wide Commanding & Sensor Data Transmission Infrastructures

Worldwide Control via Cloud Computing!

Fink et al., CMPB 2009; SPIE 2009

Controllable worldwide via iPhone (demonstrated at MacTech 2010 Conference)

Communications Server(s)

Wireless Internet

Cloud Computing

Internet

Deployed Agents

Control System

Image Processing Application
Operational Autonomy & Anomaly Detection

A new field for PHM?!
Automated Global Feature Analyzer (AGFA, Fink et al., 2008)
Operational Level 1 Diagram
AGFA
Example Imaged Operational Area

[MER Image Courtesy NASA]
Example Target (Rock) Features

- Color
- Angularity
- Albedo
- Texture/Vesicularity
AGFA (Fink et al., 2008)
AGFA Anomaly Detection: Conceptual Example
Preliminary Feature/Reconnaissance Data (coarse)

Raw Sensor Data

Fink, IEEE WCCI 2006
Preliminary Feature/Reconnaissance Data (coarse)

Target Identification

Fink, IEEE WCCI 2006
Preliminary Feature/Reconnaissance Data (coarse)
Target Prioritization

Fink, IEEE WCCI 2006
Ground-Truth

Follow-up (In-situ) High-resolution Sensor Data

Fink, IEEE WCCI 2006
Formulation of Working Hypotheses
Test Scenario: Fluvial Event

Pre Geologic Process Situation
Formulation of Working Hypotheses

Test Scenario: Fluvial Event

Geologic Process, e.g., fluvial
Formulation of Working Hypotheses
Test Scenario: Fluvial Event

Post Geologic Process Evidence as “seen” by the Rover
Formulation of Working Hypotheses
Test Scenario: Fluvial Event

“Seen” as 3 different deposits?

If so, geologic history of this region may be unclear/random!
“Seen” as 2 different deposits?

If so, geologic process may have taken place in the past, e.g., flood!
Extraterrestrial Outlook
Future Space Exploration Missions

Mars

Titan
Contact Information

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