Presentation to SICE 2007

Robotic Space Exploration Technology Development and Mission Infusion

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Outline:

1. Intro to JPL and Planetary Exploration Mission
2. Intro to JPL Robotics
3. Flight Project Applications
   - Mars – MER, MSL, Phoenix
   - Moon
   - Titan and Venus
4. Terrestrial Research and Applications
5. Summary
NASA Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
The Solar System...

— "Planets" —

Mercury  Venus  Earth  Mars  Jupiter  Saturn  Uranus  Neptune

— "Dwarf Planets" —

Ceres  Pluto

...and some of JPL's past robotic explorers.

RANGER  MARINER  PIONEER  VOYAGER  MAGELLAN  GALILEO  CASSINI
Planetary Targets for Upcoming Robotic Exploration *In Situ*

- **Venus** (by airship)
- **Earth** (for comparison)
- **Small Bodies** (by rendezvous)
- **Moon** (by rovers & landers)
- **Mars** (by rovers & landers)
- **Titan** (by airship)
JPL’s Mission as it relates to JPL Robotics

A primary component of JPL’s mission is to explore the solar system. Techniques to do this include:

- Astronomy
- Remote / Orbital Sensing
- Entry, Descent, and Landing (EDL)
- In Situ Exploration, including
  - Sampling
  - Surface Mobility
  - Aerial Mobility
  - Subsurface Access

JPL Robotics is focused on enabling all modes of In Situ Exploration, as well as improving other areas such as EDL.
JPL Mobility and Robotic Systems Section Overview

Richard Volpe
Section Manager

Gabriel Udomkesmalee
Deputy Section Manager

Allen Sirota
Robotic Hardware
Systems
• Mechanical and electrical design, fab, test
• System engineering

Issa Nesnas
Robotic Software
Systems
• Software system design, implementation, and test
• System engineering

Paul Backes
Mobility and Manipulation
• Algorithm design, implementation, and test
• Experimentation and validation

Larry Matthies
Computer Vision
• Algorithm design, implementation, and test
• Experimentation and validation

G. Udomkesmalee (AD)
Advanced Robotic Controls
• Fuzzy, Neural, Behavior and other advanced control algorithm design, implementation, and test
• Experimentation and validation

- System capabilities mirror JPL as a whole.
- Over 30 years of robotic system development
- Over 80 engineers, plus management
- For more info see http://www.robotics.jpl.nasa.gov
JPL Robotics Application Areas (1/2)

Driving... on Mars, with terrain analysis

Sampling... surface soil & ice, and rock drilling

Manipulation... on Mars with 5 DoF or lab with 8

Subsurface Access... through ice and regolith

Flying... Venus and Titan concepts

Landing... Mars results and future
JPL Robotics Application Areas (2/2)

Orbit determination around Small Bodies

Approach and Instrument Placement

Physics-based Simulation of Surface, Aerial, and Landing Scenarios

Mission Operations User Interfaces

Military and Terrestrial Systems

Cooperative systems and innovative concepts
**Key points**

- Robotics technologies span all of JPL, but represent a discipline by themselves.
- JPL has been home to one of the largest, sustained robotics development teams worldwide.
- Before 1990, robotic manipulation was the major area of research for JPL Robotics
  - more recent rover-based manipulation focus feels like a return to the past.
- Since Pathfinder, there has been a steadily growing mainstream participation in flight projects
- Regarding aerial systems, we are now at the same point we were 15 years ago with rovers.
Flight Project Applications:

Pathfinder: Sojourner Rover (1997)
MUSES-CN: 1kg rover (2000)
MER: Mars Exploration Rovers (ongoing from 2003)
Phoenix: Robotic Arm (2007 launch)
MSL: Mars Science Laboratory (2009 launch)
2003 Mars Exploration Rovers (MER)
MER Mars Rover Update – Opportunity

- **Mission:** Prime mission was 90 days and 600m, but... now at 1300 sols and 11 km
- **Plans:** Next objective is entrance to Victoria crater with slopes >25 degrees, to observe layered terrain.
- **System:** One dead steering joint, and age of one manipulator shoulder joint is showing.
- **Terrain:** Terrain has been smooth with sand with hematite “blueberries”, and intermittent craters.
- **Weather:** Recent struggles with dust storms reducing light and temperatures, and covering solar cells
**MER Mars Rover Update – Spirit**

- **Mission**: Prime mission was 90 days and 600m, but... now at 1300 sols and 7 km
- **Plans**: Continued study of geology near “homeplate” feature.
- **System**: Mobility system is showing its age – one wheel drive is dead.
- **Terrain**: Rough and rocky, more craters, hills.
- **Weather**: Struggles with dust storms, but regular dust-devils providing cleaning events.

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**Images**:
- Rover and tracks viewed from orbit
- Dust devils and sunset during clear weather
- Before and after cleaning event
- Rover and tracks viewed from orbit
- Dust devils and sunset during clear weather
MER Movies

Spirit Long Drive Telemetry

Autonomous Navigation Tutorial
Contributions to MER by JPL Robotics

- **SAP / Maestro** for science activity planning [PI: Jeff Norris]
- **RSVP** for sequence planning
- **DIMES** for entry, descent, & landing (EDL)
- **Stereo Vision** for surface hazard detection
- **Visual Odometry** for surface position estimation
- **GESTALT** for surface navigation
- **Manipulator control** algorithms and software

And in the latest MER software release...

- **Autonomous Visual Target Tracking** while driving toward science goals
- **Autonomous Visual Arm Collision Check** with terrain before deployment
- **CMU D* global path planning** to complement to GESTALT local path planning
- **Autonomous Dust Devil visual detection** for capture of science events
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Upcoming Mars Missions
2009 Mars Science Laboratory

Robotics contributions:

1. All MER technology
2. Improvements on MER baseline in all areas.
4. Design, development, and operations staff.
MSL Movies

Mechanical System Drop Test

EDL and Surface Ops animation

Mechanical System Drop Test
2007 Phoenix Mars Lander

Robotics contributions:

1. Manipulator control  [Bonitz]

2. Operations tools:
   - collaborative science planning software system (Maestro/PSI)  [Norris]
   - robot sequence and visualization (RSVP)  [Cooper]

3. Visual hazard analysis of landing sites  [Cheng]

4. Simulation of entry and descent for mission planning  [Balaram]
The Phoenix Mission is led by Principal Investigator Peter H. Smith of The University of Arizona, supported by a science team of CO-Is, with project management at NASA's Jet Propulsion Laboratory and development partnership with Lockheed Martin Space Systems. International contributions for Phoenix are provided by the Canadian Space Agency, the University of Neuchatel (Switzerland), the University of Copenhagen, and the Max Planck Institute in Germany.
Mission Driven JPL Robotics Research
Improved On-board Autonomy for Mars

**AUTONOMOUS TRAVERSE:**
Go further and more accurately through more difficult terrain, while maintaining safety.

**APPROACH & INSTRUMENT PLACEMENT:**
Enable autonomous placement of a science instrument on a designated target, specified in imagery taken from a stand-off distance.

**ONBOARD SCIENCE:**
Enable autonomous processing of science data onboard the rover system, for intelligent data compression, prioritization, anomaly recognition, or target selection.

**SAMPLING:**
Improve sampling, sample processing, and sample caching through development of techniques or new system components.

*Then combine them!!*
Steep Terrain Access Systems for Mars

- water seepage and rock layering are science drivers.
- current 'rocker-bogey' systems limited to ~30 deg slopes.
- new system concepts are being explored. Typically tethered for access down steep terrain.
Robotic Exploration of the Moon
Mission Driven JPL Robotics Research – The Moon

Limbed Mobility

- ATHLETE: All-Terrain Hex-Legged Extra-Terrestrial Explorer

Operations

- Maestro and RSVP: adaptations to Lunar mission profile with time delayed teleoperation

Autonomous Landing

- ALHAT: Autonomous Landing and Hazard Avoidance Technology
ATHLETE Lunar Mobility Prototype

‘All Terrain Hex-Legged Extraterrestrial Explorer’

[PI: Brian Wilcox]

Tandem traverse and automated docking

Steep terrain driving and walking

Tool use for augering, plowing, and grasping

Astronaut habitat transport demonstration

ATHLETE operations system (COACH)
Three ATHLETEs in the lab during docking tests.
ATHLETE Movie
Aerial Exploration of Titan, Venus, & Mars
JPL and its partners achieved several important milestones in the development of planetary aerobots:

- Fabricated a full-scale prototype helium balloon for Venus and demonstrated leak-free performance. Technology is applicable to a 2 week, high altitude (55 km) mission.

- Accomplished the first successful aerial deployment and inflation of a prototype Mars helium spherical balloon in a stratospheric flight test.

- Fabricated and successfully tested a one-third scale helium-filled Titan blimp prototype at cryogenic temperature (93 K).

- Demonstrated autonomous flight control of a larger Titan testbed airship using simulated and real systems.
Technology Development back on Earth
CLARAty Robotics Software

'Coupled Layer Architecture for Robotic Autonomy'

[PI: Issa Nesnas]

- **Background:** Enhancing robotic intelligence requires the integration of advanced technologies from multiple disciplines and their deployment on real platforms in uncertain environments. Historically, software that embodies such intelligence was uniquely developed for each robot, thus impeding the use of technologies across projects.

- **Technology:** A collaborative effort of JPL, NASA Ames, Carnegie Mellon and U. of Minnesota, funded by the Mars Technology Program, has developed the CLARAty reusable robotic software system. CLARAty integrates technologies developed by competed NASA programs and demonstrates such technologies on real and simulated robots at multiple institutions. Examples include autonomous targeted driving with vision-based obstacle avoidance in rough terrain.

- **Status:**
  - Released a portion of CLARAty to the public on June 13, 2007
  - Software includes 44 modules and a 100K lines of code
  - Functionality includes robotic math, coordinate transforms, motion control, mechanism models, and vision

- **Impact:**
  - Strong interest among general public and robotics community.
  - Tens of web sites carried articles on the release
  - CLARAty site received around 2.5 million hits in two months
  - Total of 3,300 downloads of the software in one month
  - Hundreds of comments from the community.
Physics Based Simulation: DARTS / Dshell

'Dynamics and Real-Time Simulation'
[PI: Abhi Jain]

INFRASTRUCTURE

- **Computational Multibody Dynamics**: Spatial Algebra framework; Mass Matrix factorization; O(N) algorithms; Diagonalized & under-actuated dynamics; DARTS rigid/flexible dynamics; PyCraft workbench

- **Dshell Simulation Framework**: Real-time physics-based simulations; Reusable model libraries; High-Performance Algorithms, Multi-domain/mission; Modular extension architecture; Python scripting i/f

- **SimScape**: Terrain modeling middleware; 3D mesh and 2.5D DEM multi-modal, hierarchical models; Standard import/export

- **Dspace**: Simulation driven 3D visualization; Real-time shadows; Ray tracer and graphics hardware engines; Camera optics with distortion

SYSTEM USE

- **DSENDs EDL Simulator**: End-to-end simulation; Aerodynamics; Parchute models; Atmospheric models; Multi-body separations/reelout; Thrusters/Engine; Terrain models; navigation & imaging sensors; ephemerides; GNC models.

- **ROAMS Rover Simulator**: Rocker-bogey dynamics; wheel-soil interaction including slip; Navigation and hazard detection cameras; Rover actuators/sensors, Navigation algorithms

- **Aerobot Aerodynamics Simulator**: Buoyancy modes; Propellers/Fins; Apparent Mass. Titan atmosphere.

- **NEIMO Molecular Simulator**: Internal coordinate molecular dynamics; Biomolecular simulations; Multi-scale molecular models; Fixman potential

- **Free Flyer Spacecraft**: Spacecraft rigid/flex modes; Fuel Slosh, IMU/Star-Tracker; Rendezvous sensors; Robot assisted berthing. Cassini, Starlight, TPF, Modular Ion thrust Lunar system
DARTS / Dshell Example Movie

ROAMS and Simscape Simulation of ATHLETE on the Moon
Maestro Robotics Operations Software

[Jeff Norris, Mark Powell, et al.]

- Operations Interface
  - *Understand State:* Displays telemetry including stereo imagery, and science or engineer data products.
  - *Command System:* Allows multiple, distributed users to create a desired sequence from an application defined dictionary.
  - Runs on virtually any platform
- Used for large flight projects (MER, Phoenix, MSL) and small research efforts.
- NASA Software of the year, 2004
- Built with and on Eclipse
SOOPS ‘Field Test in a Box’ Software
‘Science Operations on Planetary Surfaces’
[Pan Conrad, Mike McHenry, et al.]

- Provide an end-to-end system for simulated missions.
- Enable testing of new autonomy algorithms and their operational utility.
- Reduce the cost of ‘field testing’.
- Train operators using realistic system performance and environmental data.
In Conclusion...
Concluding Remarks

1. JPL Robotics is addressing a broad spectrum of science driven, planetary exploration problems.

2. JPL Robotics has a successful track record of taking technology from concept to flight.

3. For more information with ongoing updates see: http://www-robotics.jpl.nasa.gov/

4. Contact me if you would like to visit...
Not an advertisement... but one has to wonder... are the stars aligning?
Questions?
Backup Information
**Additions?**

**Vision Techniques**

**Stereo vision perception of environment**

**Manipulator Visual Position Correction**

**Terrain Relative Guidance while Driving**

**Rock Detection for Avoidance and Targeting**

**Visual Dust Devil and Cloud detection on Mars**
MER Opportunity Gets Stuck

*Before escape*  

*Afterwards*
DISTRIBUTED MOTOR CONTROL

SUMMARY

Greg Levanas, Electronics Lead

- Electromagnetic motors are becoming more common place on space vehicles.
- Typical applications include deploy actuators, antenna position, instrument platform pointing, science instrument mechanisms...etc.
- Mobility systems greatly expand the use of flight motors both in quantity and application.
- To support larger motor counts on space vehicles distributed electronic architectures are highly desired.
- In addition extreme temperature electronics are desired to enable distributed electronic motor systems being placed where they work best at the back of a motor.
Mission Driven JPL Robotics Research – Other Planets

Subsurface Access

- **Cryobot**: melt through Jovian icy moons’ surfaces to oceans below
  (also possible for Mars polar regions)
  POC: Al Sirota, Wayne Zimmerman

Small Body Access

- **Small Body Navigation**: Image Processing Techniques for Sensing, Estimation, Control
  POC: Yang Cheng

Aerial Access

- **Titan, Venus, Mars**
  - Materials validation
  - Mission design
  - Titan autonomy for station keeping, surface rendezvous, required by long communication delays and planetary occultation
  POCs: Jeff Hall, Alberto Elfes
End of File