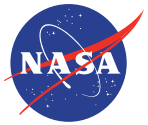


Jet Propulsion Laboratory
California Institute of Technology

Overview of JPL Robotics

Brett Kennedy
Jet Propulsion Laboratory
California Institute of Technology

JPL Overview

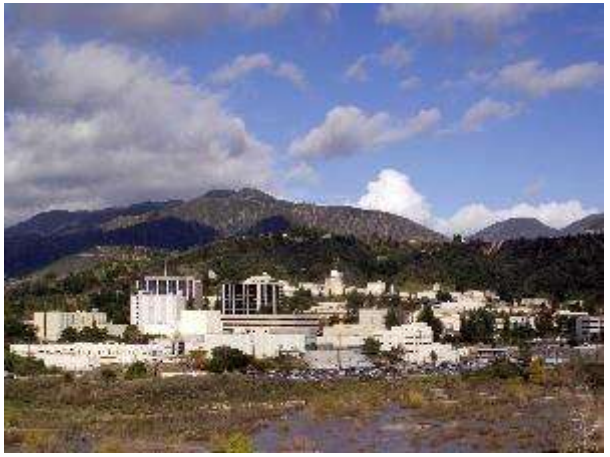
US Federally Funded Research & Development Center in Pasadena, CA

One of 10 NASA centers

Founding dates to 1930s

Currently operating 22 spacecraft, 2 rovers and 10 instruments in space

Responsible for many space firsts:

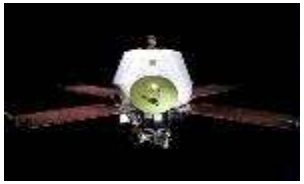


1st U.S. satellite
Explorer 1 - Jan 28, 1958

1st close-up images of another planet
Mariner 4 to Mars - Nov 1964

1st fly-bys of Neptune and Uranus
Voyager 2 - 1986 & 1989

1st U.S. spacecraft to the moon
Ranger 7 - Jul 28, 1964



1st orbiter at another planet
Mariner 9 to Mars - May 1971

1st orbiter at Jupiter
Galileo 1979 - 1989

1st planetary mission
Mariner 2 to Venus – Dec. 1962

1st gravity assist mission
Mariner 10 to Venus - Feb 5, 1974

1st orbiter at Saturn
Cassini 2004 - present

1st rover on Mars
Mars Pathfinder July-Sept. 1997

JPL Technical Expertise

Planetary Science

- Spacecraft to observe the planets, their moons, the sun, comets, and asteroids

Earth Science

- Spacecraft and instruments observing the Earth
- Studying geology, hydrology, ecology, oceanography, gravity and climate

Deep Space Astronomy and Physics

- Observatories and telescopes observing deep space
- Studying galaxy, star and planetary system formation
- Mapping our Milky Way galaxy and the universe
- Finding planets on other star systems

Technology

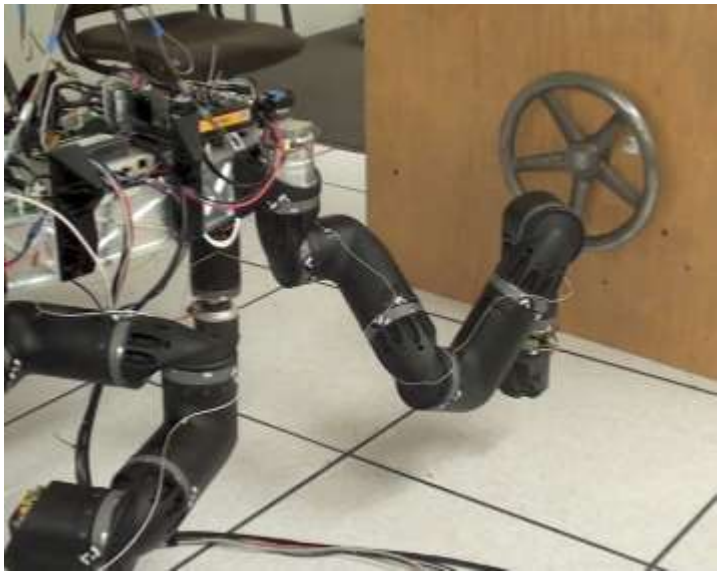
- Support space missions
- Develop technologies in telecommunications, navigation, intelligent automation, remote sensing, imaging and imag analyses, robotics, science instruments and micro/nano-systems

JPL Robot Technologies

- Robot platforms
- Physics-based simulation and visualization
- Mobility and manipulation
- Perception
- Advanced control
- Automation and intelligence
- Operator interfaces
- Maritime Autonomy

Robot Platforms

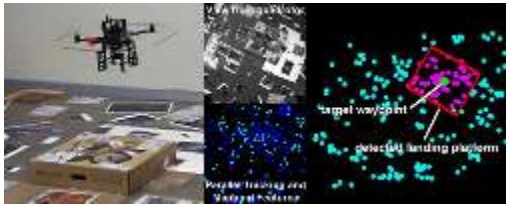
- Wide variety of robot platforms
- End-to-end platform development capability
- Developed in-house and customized commercial-off-the-shelf
- Developed for NASA and commercial, civil, and defense applications
- Range of sizes, shapes, masses, precision, strength, dexterity, etc.
- Harsh environments, reliability, durability
- Lifecycle and environmental testing



Robosimian

Unmanned Sea Surface Vehicle

Mars Phoenix Mission Robot Arm Model



Autonomous quad-rotor operations

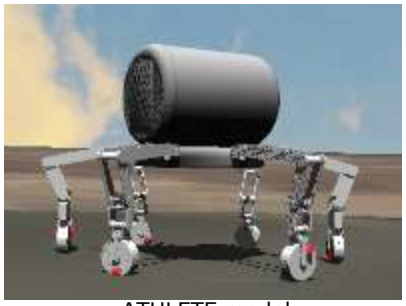
Rocky 7 rover

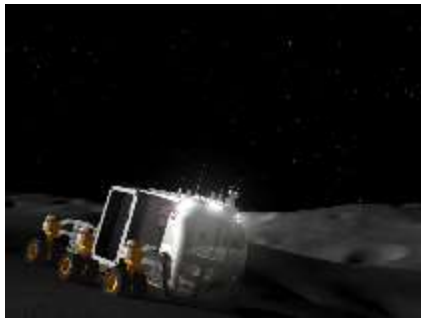
ATHLETE

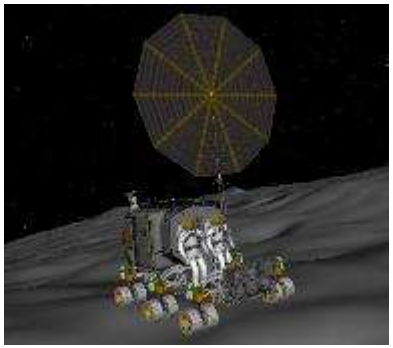
JPL Aerobot

Physics-Based Simulation

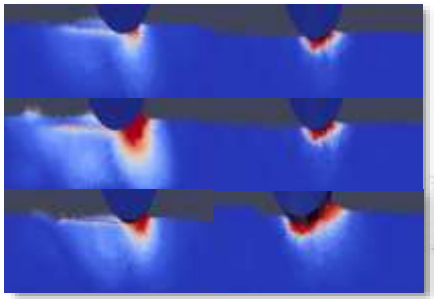
- High-fidelity physics-based modeling and simulation
- Used on MER, MSL, Cassini, Galileo and other missions and many robotics research tasks
- Capabilities:
  - Large high-resolution terrain models
  - Contact dynamics and complex mechanisms
  - Terra-mechanics, aerial, surface and sub-surface models
  - Incorporates thermal, power, communication and other dynamics
  - Parametric analysis and Monte-Carlo simulations
  - GPU-based techniques for computation

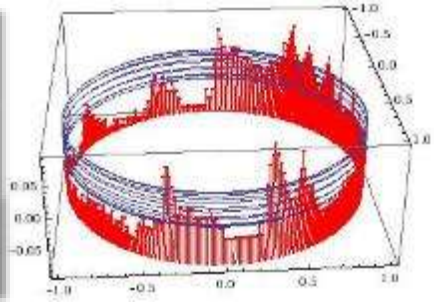

ATHLETE model


Lunar Electric Rover on the moon


Simulated Lunar Electric Rover model


Aerobot model


Granular media model of wheel-soil interaction


Solar illumination at the South Pole of the Moon

Mobility & Manipulation

- Integrated hardware, software and algorithms
- Customized solutions for particular problems
- Mobility for systems that walk, drive, climb, crawl, climb, rappel, fly, etc.
- Algorithms for manipulation, gripping, drilling, placing instruments, collecting and caching samples
- Cooperative robot operations
- Sensor-guided operations

Sample caching mechanism

Rock drilling

Rappelling a cliff with AXEL robot

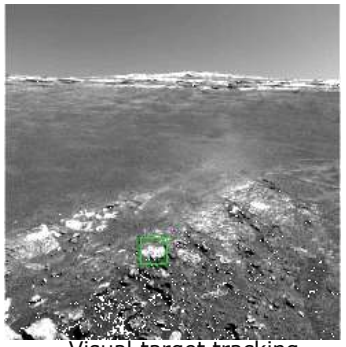
Cooperative beam transport

Perception

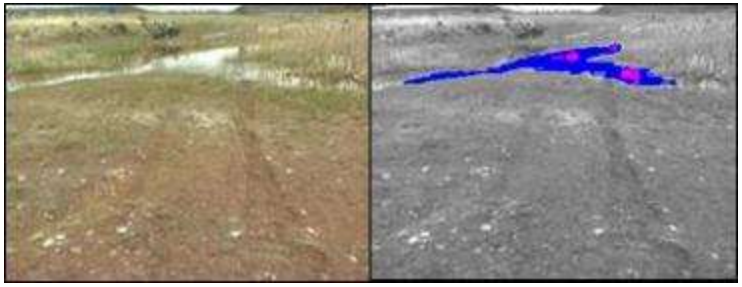
Develop models from sensors in real-time

- Stereo-vision
- Environment classification from texture
- Target tracking
- Structure from motion
- Aerial Surveillance
- Object recognition
- Activity recognition
- Shape from shadow/shading
- Odometry
- Force/position/self sensing
- Advanced sensors
  - Spectrometers, imagers
  - *In-situ* Chemistry

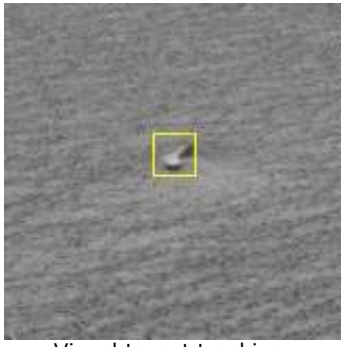
Terrain classification: safe traverse region



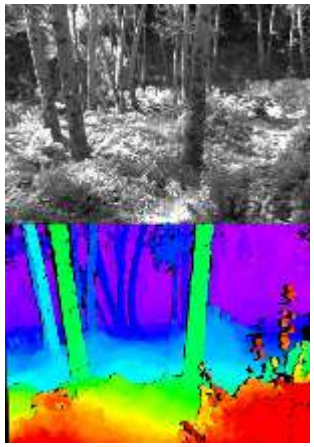
Visual target tracking



Terrain classification: water detection

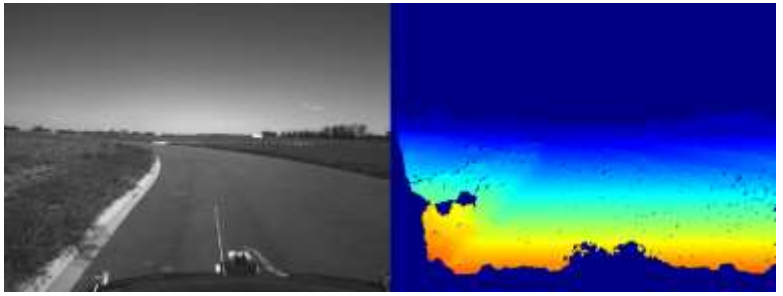


Visual target tracking



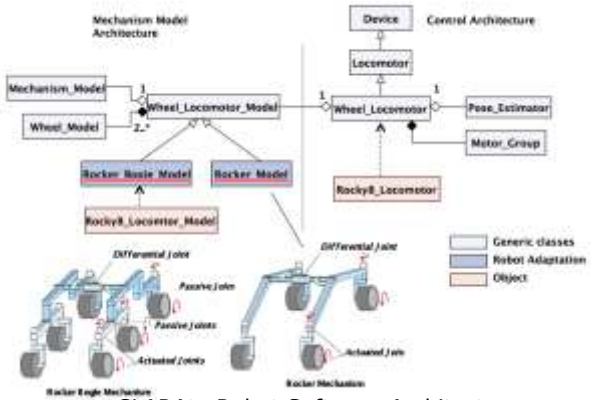
Real-time stereovision

Real-time stereovision

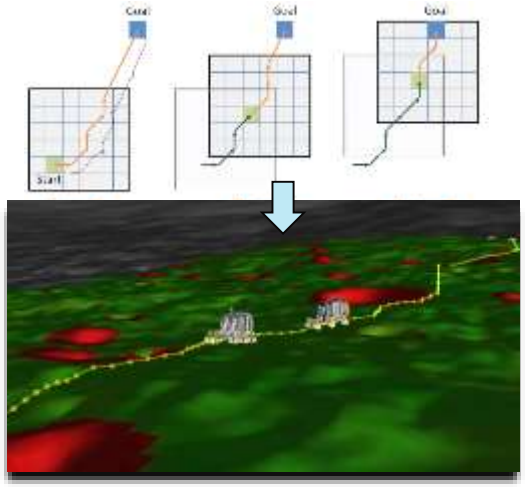


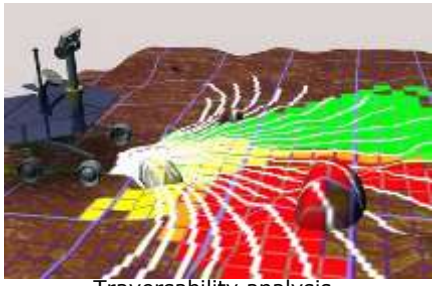
Advanced Control

- Software architectures
- Map building
- Navigation
- Traversability
- Path planning
- Optimal resource utilization
- Teleoperation
- Neural & bio-electric (EMG/EEG)sensor prosthetic interfaces
- Robot machine learning, cognition and decision making

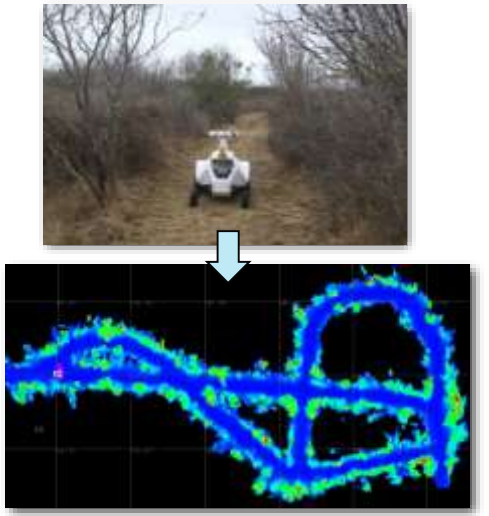


CLARAty Robot Software Architecture


Path planning to avoid hazards

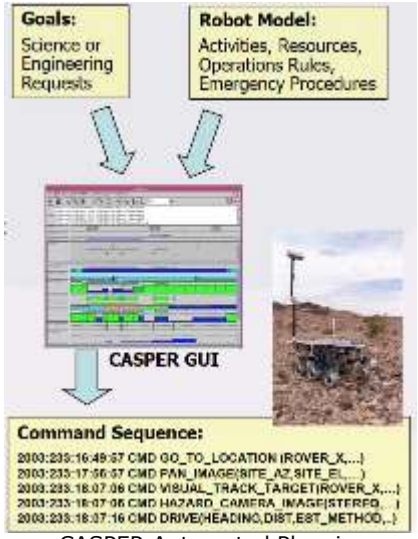

Traversability analysis


Tele-robotic micro-surgery

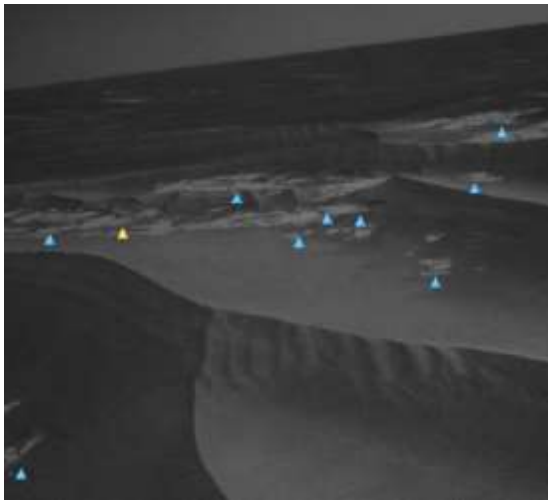

Simultaneous Localization and Mapping

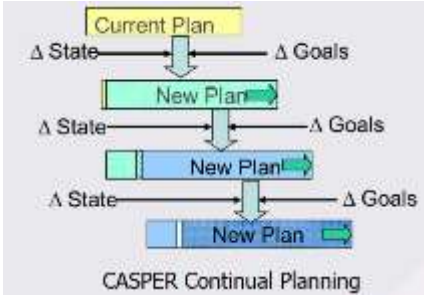
Autonomy & Intelligence

- Automated generation and modification of command sequences
- Continuous re-planning to optimize use of resources to achieve goals
- On-board science
  - Respond to dynamic opportunities – autonomously recognize a science event or target
  - Prioritize data for down-link – send the most interesting information first



CASPER Automated Planning System


Automatic rock identification and classification



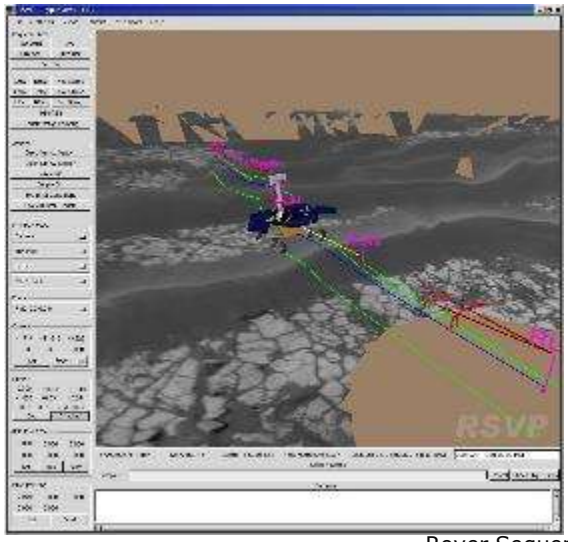
CASPER Approach

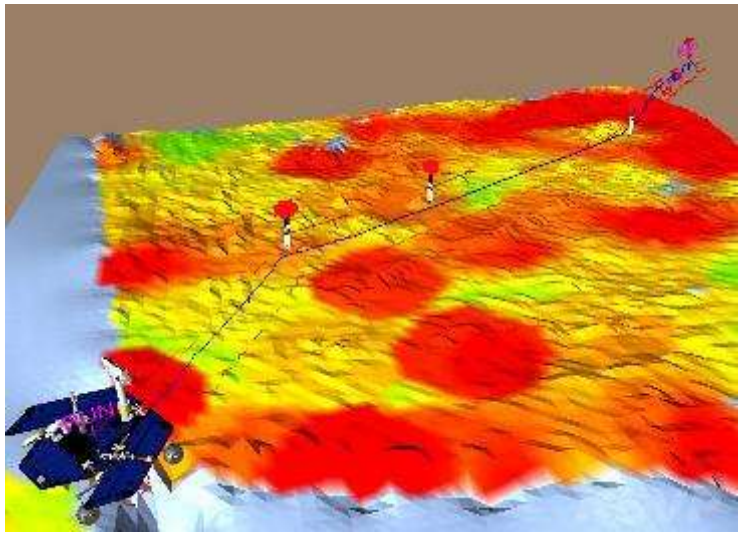

Re-plan activities to optimize science

Operator Interfaces

- Virtual or augmented reality
- Engineering data visualization
- Command sequence generation & scripting
- Operations simulation & rehearse
- Safety verification

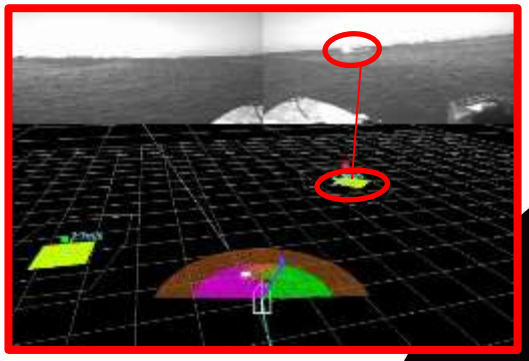
Lunar Rover Simulation Interface

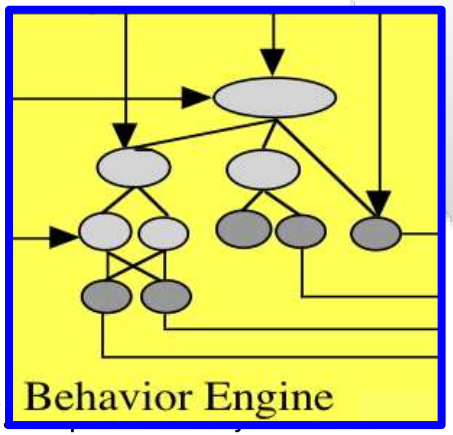


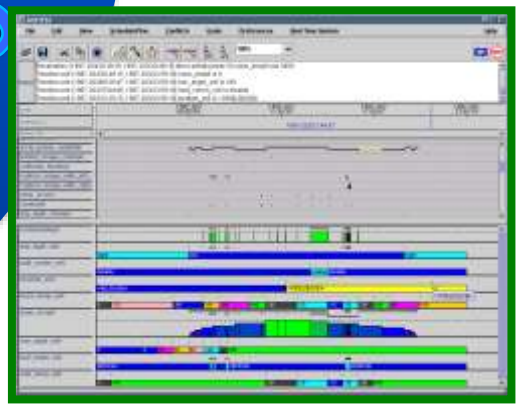


Rover Sequencing & Visualization Program (RSVP)

JPL Maritime Autonomy Technology







Maritime Technology Snapshot

JPL under contract since 2004 with US Navy, OSD, DARPA, and commercial partners to transition NASA flight-derived intelligent autonomy technology to unmanned surface and underwater boats

AIM

Develop and demonstrate advanced behaviors and capabilities for intelligent US Navy mission-level autonomous control and long duration operation of ASVs & AUVs operating under sparse advisory control and with onboard self-contained sensing and decision making.

Demonstrated "*Full-Scale" autonomy*:

- Sensor systems and situational awareness
- Tactical planning and control
  - Hazard avoidance, COLREGS compliance
  - Search, intercept & inspect, track & trail
- Mission planning/replanning
  - Adaptation to health, resource usage, mission progress
  - Multi-vehicle coordination
- Fault-aware operations
- Sparse operator input