Intelligent Robots for Space Applications

Dr. David Kortenkamp
NASA Johnson Space Center / Metrica Inc.
Houston TX 77058
kortenkamp@jsc.nasa.gov
http://www.traclabs.com/~korten
Motivation

- Planetary surfaces can be explored more cheaply and quickly
- Expensive and dangerous Extra Vehicular Activities (EVAs) by astronauts can be reduced
- Spin-off applications on earth
A Brief History of Intelligent Robots

- **Shakey (1966 - 1972)**
  - Sense, plan, act (SPA)
  - STRIPS planner (operators, pre and post conditions)
  - very slow!
Rodney Brooks and Subsumption

- Subsumption architecture published in 1986
- No internal models: “The world is its own best model”
- Fast, alive!

- move
- avoid obstacles
- wander
- build map

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Hybrid Systems

- Desire to have robots that are both reactive and deliberative

- Combined subsumption and planning
Probabilistic Robots

- Primarily concerned with mapping (localization) and navigation
- Try to determine most likely position of robot
AAAI Robot Competitions

- **1992 in San Jose**
  - find and approach 10 poles in large arena with stationary obstacles
- **1996 in Portland**
  - navigate an office building
  - collect moving and stationary balls
- **2000 in Austin TX**
  - serve hors d’oeuvres
  - search and rescue
Key Areas in Robotics

- Mapping and navigation
  - obstacle avoidance
  - mapping
  - path planning
- Computer vision
  - stereo vision
  - color vision
- Architectures
Obstacle Avoidance

- **Sonar sensors**

- **Certainty grids**
Mapping

- Topological mapping
  - distinctive places
  - connection graph
  - less need for accurate location

- Geometric mapping
  - spatial relationships maintained
  - uncertainties multiply
Path Planning

• Given a start location, a goal location and a map, find a (perhaps optimal) path from start to goal

• Replanning is often necessary if information about the environment changes
Stereo Vision

- Two cameras at a fixed distance (*baseline*) from each other.
- Different perspectives of two cameras (right and left) lead to relative difference between the location of the same object in the two images, which varies by distance.

\[
\text{Distance} = \text{baseline} \times \text{focal length} = \frac{x_1 - x_2}{x_1 - x_2}
\]
Color Vision

- Image composed of red, green and blue (RGB) components
- By knowing the color characteristics of an object (and normalizing for light) specific objects can be recognized
- Solid colors are easy
- Multiple colors use histograms
Architectures

- **Planning**
  - responsible for time and resource constraints

- **Sequencing**
  - conditional activation of skill sets

- **Control**
  - skills provide reactive control of robot
Planning example

(Operator replace-batteries
  :purpose (state batteries replaced)
  :agents (?robot ?human)
  :constraints ((instance-of ?robot 'robot)
                (instance-of ?human 'human))
  :preconditions ((state bay opened))
  :plot (sequential
          (covers
            (monitor-batteries ?robot in-monitor)
            (display ?human monitored)
            (batteries ?robot are-replaced))
          :effects ((state batteries replaced))))
Sequencing example

(define-rap (arm-move ?arm ?place)
  (succeed (and (arm-at ?arm ?where)
                (= ?where ?place)))
  (method robot-move
    (context (and (LOA arm-move ?arm ?place ?loa)
                  (= ?loa autonomous)))
    (primitive
     (enable (:arm_move (:place . ?place)))
     (wait-for (arm-move-done ?arm ?place ?result)
              :succeed (arm-move ?result))
     (disable :above)))
  (method human-move
    (context (and (LOA arm-move ?arm ?place ?loa)
                  (= ?loa tele-operate)))
    (primitive
     (tell-user "move arm to ?place")
     (wait-for (arm-move-done ?arm ?place ?result)
              :succeed (arm-move ?result)))))
Intelligent Robots in Space

- Planetary rovers
  - exploration
  - preparation
- In-orbit operations
  - astronaut assistance
- Future applications
  - on-going NASA research
Rovers

• Sojourner (part of the Mars Pathfinder mission) was first mobile robot on Mars
• Simple on-board hazard avoidance (using laser ranging, imaging and internal sensors)
• Mostly up-linked targets on regular basis
• Some path planning
Future Rovers

- NASA to send two rovers to Mars in 2003 (will land in January 2004)
- Large (~130kg)
- 90 day mission, 100 meters each mission day
In-orbit operations

- **AERCam Sprint**
  - provides a moveable camera view
  - flew on STS-87 in 1997
  - no real autonomy

- **Shuttle Remote Manipulator**
  - not really a robot
  - no autonomy
Research Robots

- **Robonaut**
  - humanoid robot
  - teleoperated
- **EVA Robotic Assistant**
  - assists astronauts on Mars
  - fully autonomous
- **Antarctica**
  - meteorite search
Conclusion

• **Robots require:**
  – sensing (vision, range)
  – actuation
  – control
  – artificial intelligence

• **Space robots becoming more capable and autonomous**

• **Robots beginning to become real**
Further Reading

• Mobile Robots and Artificial Intelligence: Case Studies of Successful Robot Systems
  – David Kortenkamp, Robin Murphy, R. Peter Bonasso, editors
  – MIT Press or Amazon.com