Robotic Platforms for Implementation of Space Infrastructure

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To-Do List

- Motivation for space construction robots
- Philosophy of space construction robots
- Robotic Construction Crew (RCC) platforms
- Lemur II platform
- Common System Elements
Motivation: Surface Outpost Construction

- Cooperative teams:
  - Large-scale
  - Many different tasks
  - Efficient and reliable

JPL Artist’s conception of robotic construction

JSC Artist’s conception of deployable lunar habitat
Motivation: On-Orbit Construction

- Sustained operations:
  - Mobility on delicate structures
  - Manipulation on delicate structures
  - Many different tasks
  - Efficient and reliable

Artist’s conception of on-orbit construction
Philosophy of Space-Construction Robots

- Putting stuff up is expensive
- There are “un-preplannable” problems
  - micrometeorites make odd holes
- Ergo: Operational flexibility is important
  - smart (Ever gotten an ant to do something useful? Ever needed to build an ant hill?)
  - dexterous (don’t maintain with cranes)
  - reconfigurable (unexpected jobs, bang-for-buck)
  - multi-purpose features
Challenges

- Maintaining rigid formations and performing precision motion in natural terrain or microgravity
- Moving and working in situations where force (both strong and weak) is important
- Fusing noisy and limited sensing (vision, motion, force-torque)
- Heterogeneous robots
- Limited processing

Robotic Construction Crew, JPL
Robotic Construction Crew (RCC)

Robotic Construction Crew approach a beam for pick-up
Robotic Construction Crew

- Leader-follower control ensures common actions and parallel execution

- Force-torque feedback helps maintain formation and prevent catastrophic failures

RCC robots approach the structure for drop-off

The RCC structure is representative of future surface infrastructure
RCC Task Video

Robotic Construction Crew

JPL
Lemur II
Platform Layout

- Axisymmetric
  - Omni-directional mobility (in plane)
  - Omni-directional manipulation (in plane)
  - Omni-directional vision (in plane)
- 6 limbs
  - 2 minimum for manipulation
  - 3 minimum for zero-moment stance
  - 1 spare
Limb Design

- 4 degrees-of-freedom
- Kinematically spherical shoulder plus knee
- 2 in-line joints
  - Shoulder roll and yaw
  - Infinite mechanical travel
- 2 right-angle drive joints
  - Shoulder pitch and knee
  - ±90° mechanical travel
- Tool changeout
- Force feedback
- Significant use of rapid prototyping
Quick-Connect

- Snap-in connection
- Inline load washer
  - Provides axial force feedback
- Inherent torque limiting
- Compatible with electrical connectors
LEMUR’s Big Picture

LEMUR IIa
January 24, 2005
Common System Elements

All or part of the following elements have been implemented on more than 14 robotic platforms

- Avionics/Electronics
- Stereo Vision systems
- 3-Layer Software Architecture
- Application software (not an exhaustive list)
  - Low-level control
  - Machine Vision
  - Behavior-based planner
Other Examples of Robot Platforms

- MER Egress Rover
- Sample Return Rover
- Inflatable Rover
- FIDO
- MER (testing)
- Cliff-bot System
- LEMUR I
- All Terrain Rover
Avionics/Electronic Hardware

- Qualified as Flight Electronic Ground Support Equipment
- PC-104 format stack
- Modular
  - Additional boards expand I/O, motor drivers, etc...
- Driver boards built around current-control chips
Vision Systems

- Short-range stereo for hazard detection
- Long-range stereo planning
- Close-up monocular for Science & Inspection

The LEMUR stereo pair can travel along a circular track

Arm-mounted cameras for inspection

Mast-mounted cameras for navigation
Software Architecture

- Real-Time Operating System (VxWorks)
- Modular, 3-layer
- User-friendly (or at least user-tolerant)
- Deterministic

Information flow for motor control
Application Software

- Hybrid Image Plane Stereo (HIPS)
  - Dynamically updates mapping of camera model to joint-space
  - Allows for system non-linearity and graceful degradation

Left View                        Right View
Application Software (Cont.)

- Barcode data system
  - Passive
  - Non-volatile
  - Provides fiducial marks for orientation

Barcode Extraction Sequence

Sample 16-bit Barcode
CAMPOUT Behavior-Based Architecture

- Enables Cooperative and Coordinated operations of multiple agents
- Higher-level functionality is composed by coordination of more basic behaviors
- Decentralized planner
- Scaleable

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Task Behavior Network for RCC

- Implemented in CAMPOUT architecture

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**Sensing Behaviors**
- FIND FIDUCIALS
- F-T VEL CONTROL
- COMM

**Task Behaviors**
- ALIGN AT STORAGE
- ACQUIRE COMPONENT
- CLEAR STORAGE
- ALIGN AT STRUCTURE
- PLACE COMPONENT

**Action Behaviors**
- TURN IN PLACE
- DRIVE / CRAB
- MOVE ARM
- ACKER. TURN

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Robotic Construction Crew Summary

- Capabilities and Results
  - Force-torque feedback and velocity control for formations
  - Synchronization of motions with leader-follower control
  - Fusion of all available sensor data
  - Prevention of catastrophic failures
  - Low failure rate
JPL has a highly developed infrastructure geared toward space assembly and construction.

Guiding design philosophy is operational flexibility:
- Requires brains, joints, and a willingness to change (shape, tools, algorithms).
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