ICRA ’07 Space Robotics Workshop

Lessons Learned on the AWIMR Project

Rick Wagner and Hobson Lane
Northrop Grumman Corporation

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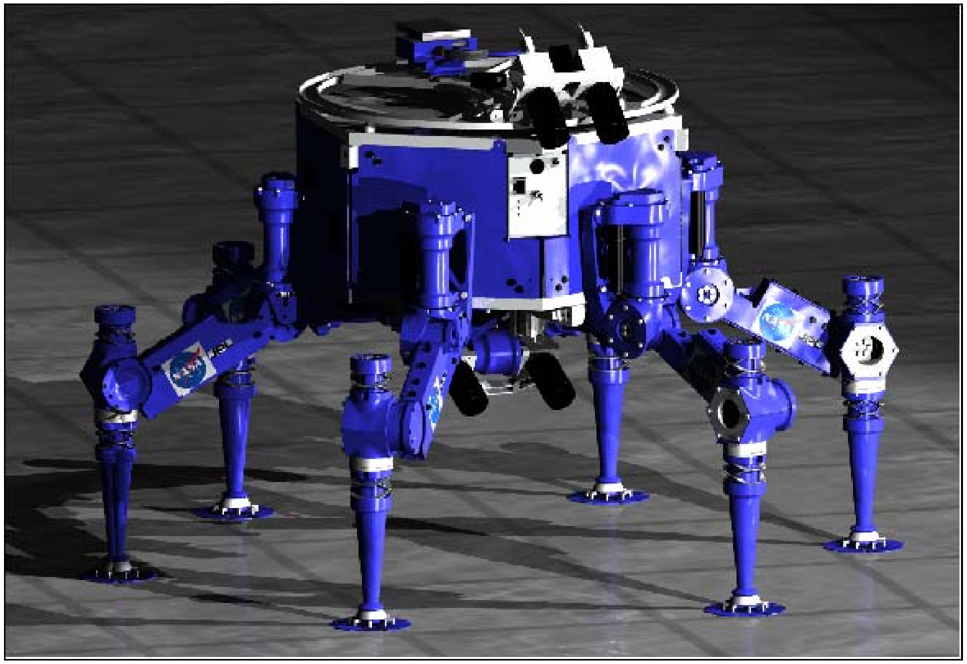
Contents

Introduction

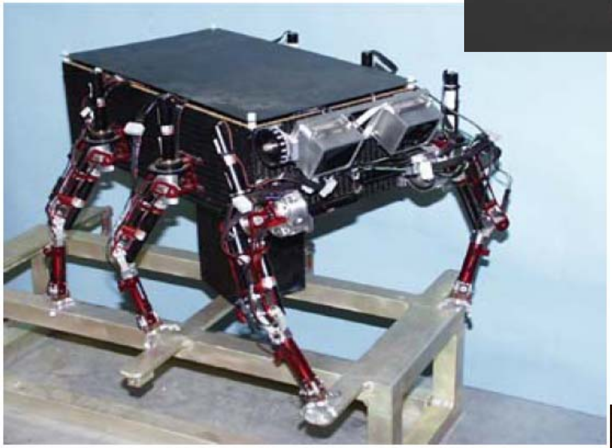
- Goal: reduce astronaut EVA time
    - Leads to a substantial reduction in mass for suits, spares, and consumables
- Solution: a walking robot to patrol the exterior of the space vehicle inspecting for micrometeorite and other damage
    - Also perform minor repairs and
    - Assist astronauts on EVA

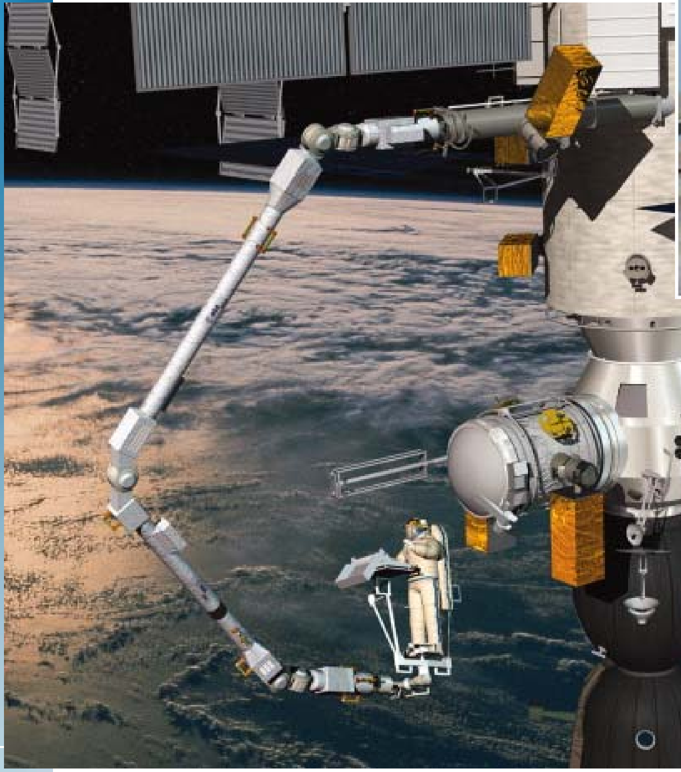


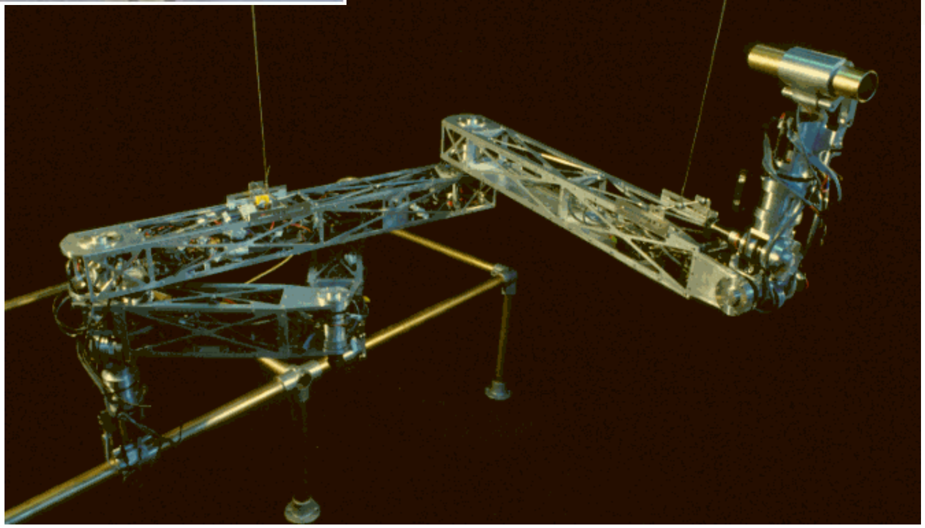
- AWIMR project began in January 2005
- Two patents filed as a result of the research
- Funding constraints cut the project short in November 2005

Related Work

- JSC's Robonaut
- JPL's LEMUR I and LEMUR II
- CMU's Skyworker
- European Robot Arm for ISS
- JSC's mini AERcam

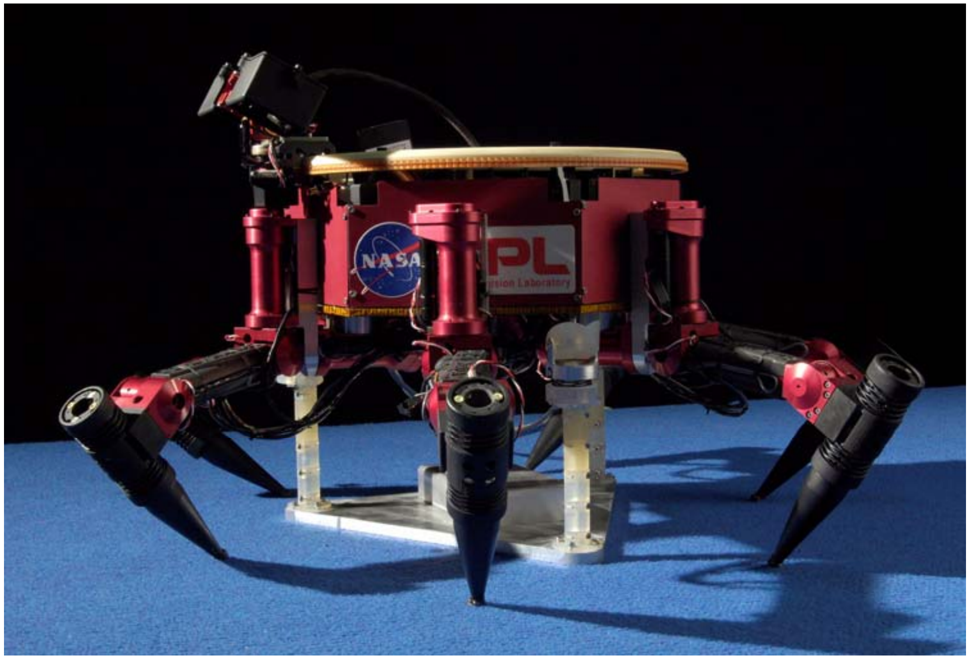


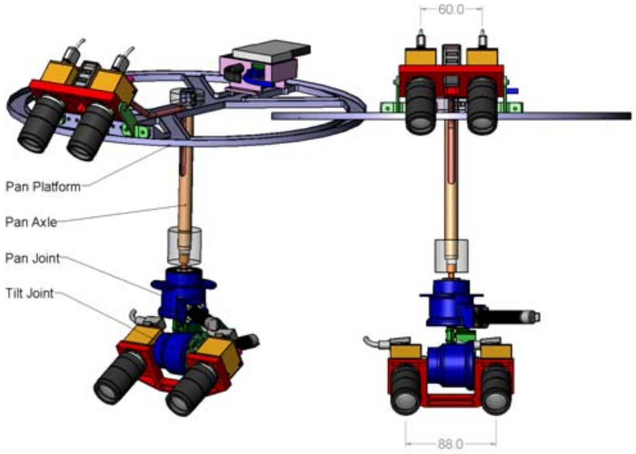


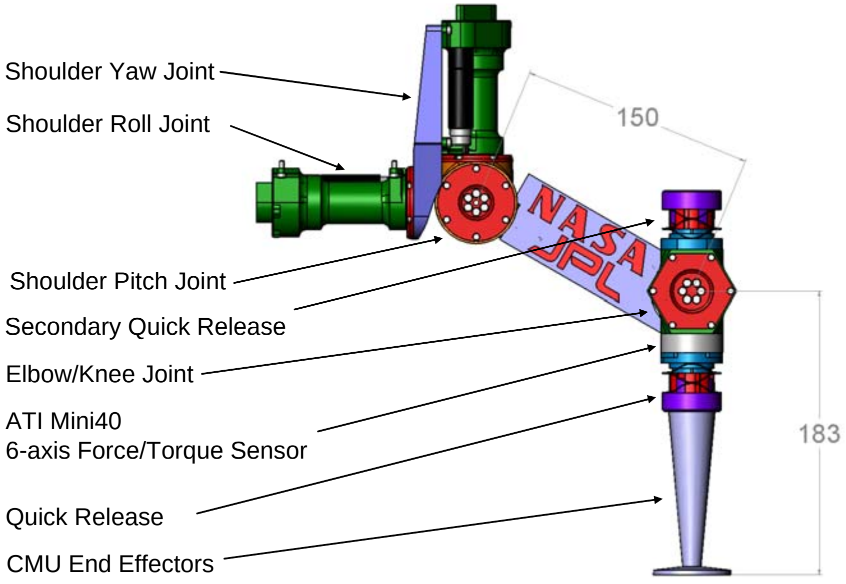


Prototype AWIMR

- AWIMR tasks:
    - Inspection for damage: patrol or directed modes, leak location
    - Simple repair work: re-attach insulation, bond cracks, tighten screws
    - Astronaut assistance
- Phase I prototype AWIMR based on JPL's LEMUR II
- Hexagonal equipment compartment, six legs, sticky feet, and two pairs of stereo cameras





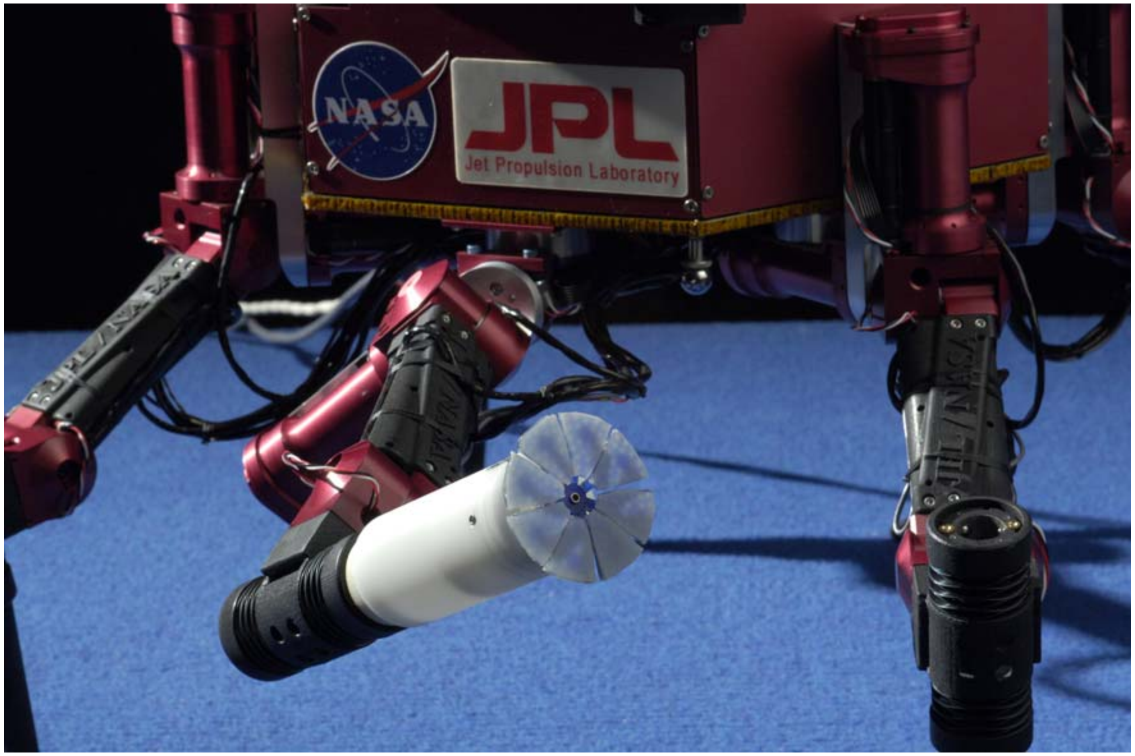


Lessons Learned: Task and Algorithm Iteration

- Task trade study
    - Perform a trade study to determine space robot task set
    - Consider tasks within a system context
    - Assign a benefit for each task
    - Task set drives algorithm conceptual design which drives hardware design
    - Hardware design determines mass, power, reliability, and complexity costs: iterate for optimal task set
- Design the robot for the optimal task set
    - Example: a robot that can do all repairs may cost too much in mass and complexity
    - Use task set scenarios (CONOPS) to find out needed capabilities and control requirements early
    - Example: speed of locomotion may be very important; how fast should the robot be? (this is a real driver on costs)

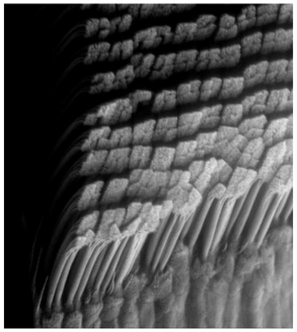
Lessons Learned: Walking Locomotion

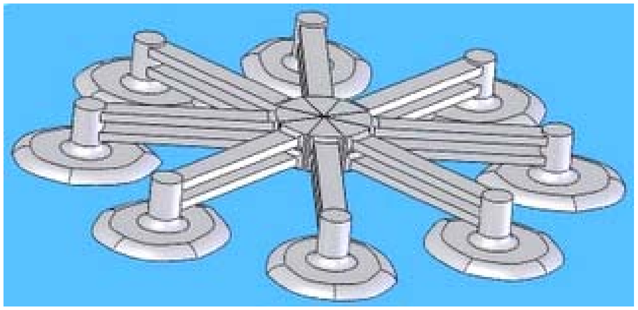
- Primary requirement: maintain a positive grip on the spacecraft!
    - Astronauts sometimes use tethers; not practical for robots
- Mechanical grippers add considerable complexity
    - Additional degrees of joint control
    - Must have something to grab at all locations
- Electrostatic and “sticky foot” grippers have their own drawbacks

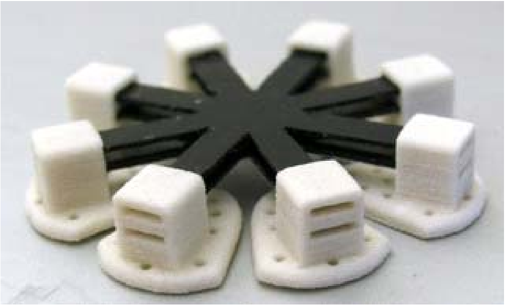


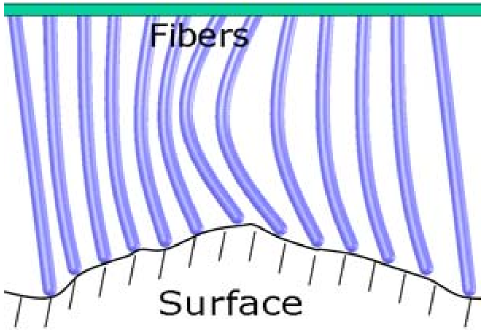
Lessons Learned: Sticky Foot

- Ripple gait
    - A single foot is moved at a time
- Tripod gait
- Pairwise opposed gait









- Can walk on any clean surface
- Requires pull-off force
- Must avoid fragile surfaces
    - Insulation blankets, solar cells, antenna mesh, etc.

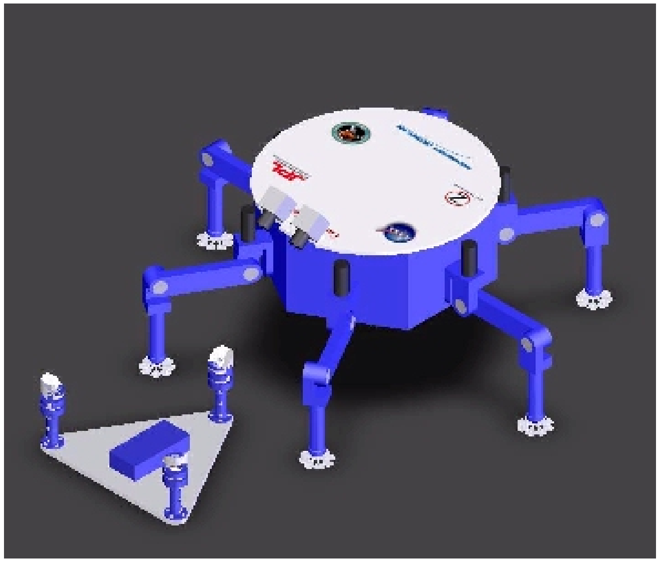
Inspired by the gecko's micro-fiber sticky foot, polymers such as polydimethylsiloxane provide repeatable sticky force greater than preloading force. We found that sticky feet require attention to the zero-g gait.

Lessons Learned: Navigation

- Routine patrol or directed movement requires re-registration at some distance from charging station
  - Machine vision for navigation adds complexity
  - Bar (block or dot pattern) codes on space vehicle can help
- Obstacle avoidance is essential
- Teleoperated mode requires a high level user interface
  - Need (joystick) commands like “go forward” and “turn right,” not “move this leg” or “move that leg joint.”
  - Teleoperated modes are essential in early testing, so think about this interface early in the program

Lessons Learned: Docking Force

- Sticky feet (in pull direction) may not have enough force margin for docking
    - Sticky feet in shear have more force capability
- Consider pull-in capability for the docking interface
    - Screw drive, toggle, or other latching mechanism
- Force feedback control could be an enabler here



Lessons Learned: Power Management

- Dynamic gaits and control for higher speed locomotion will consume more power
- Faster inspection means more bandwidth for data which means more power for RF transmission
- Battery size is a major mass contributor
- Duty cycle might be improved by using a battery drop-off strategy for recharging
- Consider a need for power margin for contingency operations

Lessons Learned: Business

- AWIMR: a partnership among business, government, and academic institutions
- NGST, as prime, has significant experience managing subcontracts
    - The unusual mix of partners requires special attention to communication and managing expectations
    - The prime needs to understand cultural differences across institutional lines
    - Get agreement early about how information handoffs are managed

Conclusion

- The feasibility of a robot to walk on the exterior of an exploring space vehicle was established
  - Inspection
  - Repair
  - Astronaut assistance
- The reduced EVA time is a potential enabler for long duration human exploration spaceflight
- The lessons documented here will assist the inevitable follow-on project