ICRA '07 Space Robotics Workshop

Lessons Learned on the AWIMR Project

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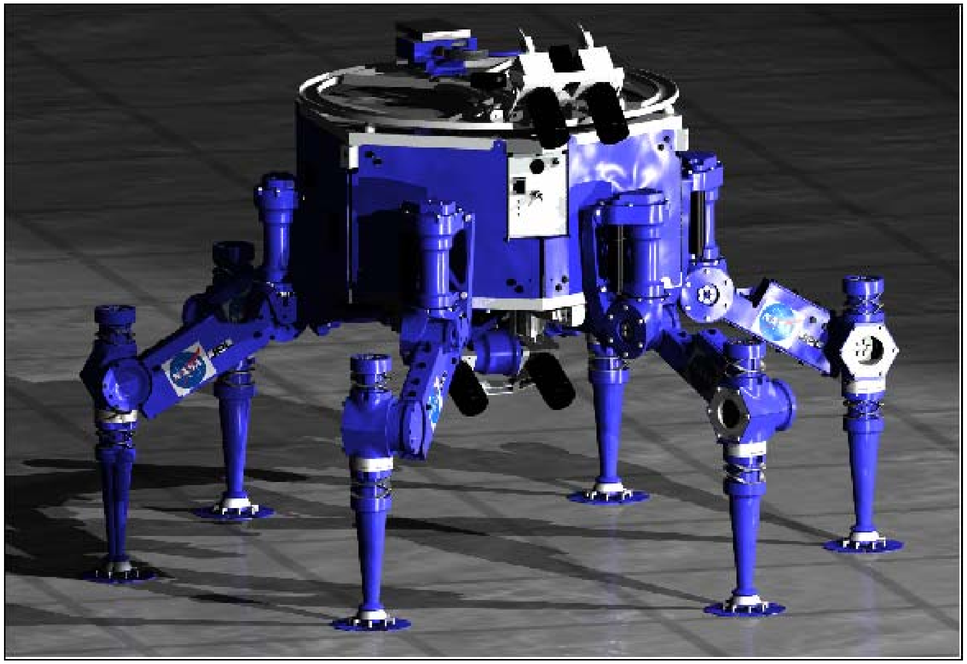
Contents

Introduction

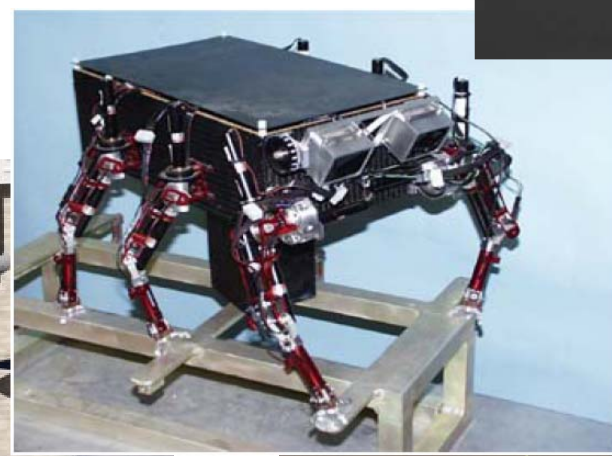
- Goal: reduce astronaut EVA time
  - Leads to a substantial reduction in mass for suits, spares, and consumables
- Solution: a walking robot to patrol the exterior of the space vehicle inspecting for micrometeorite and other damage
  - Also perform minor repairs and
  - Assist astronauts on EVA

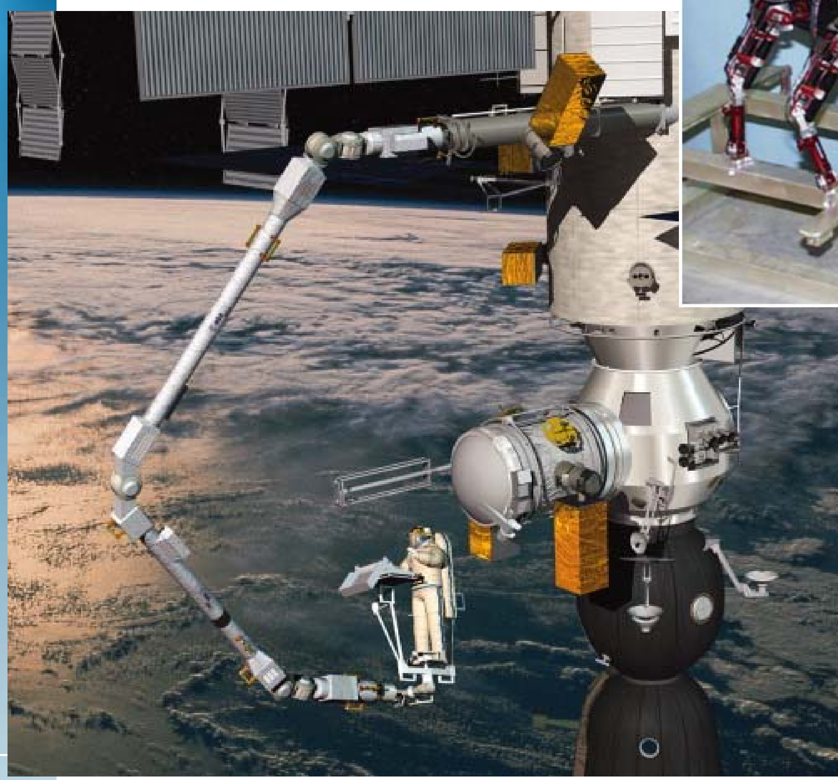


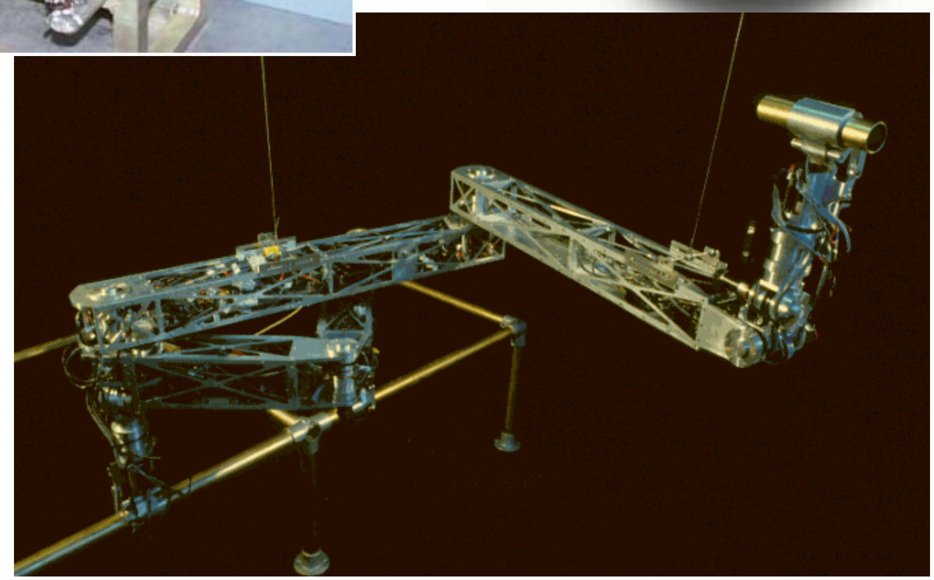
- AWIMR project began in January 2005
- Two patents filed as a result of the research
- Funding constraints cut the project short in November 2005

Related Work

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

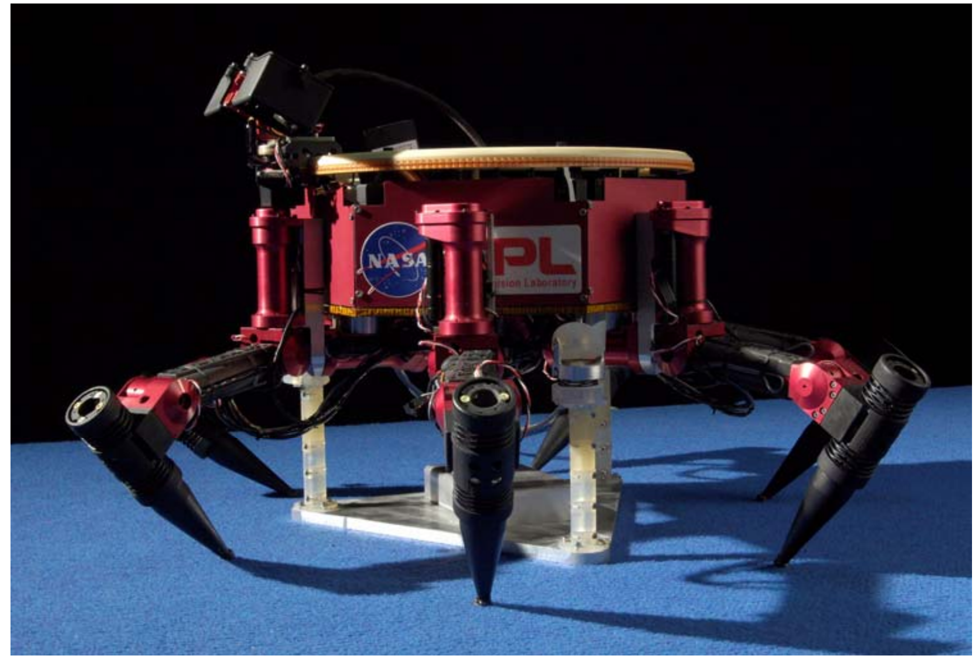


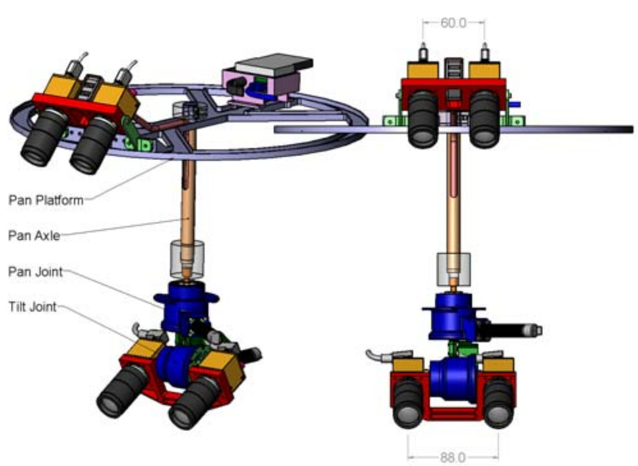


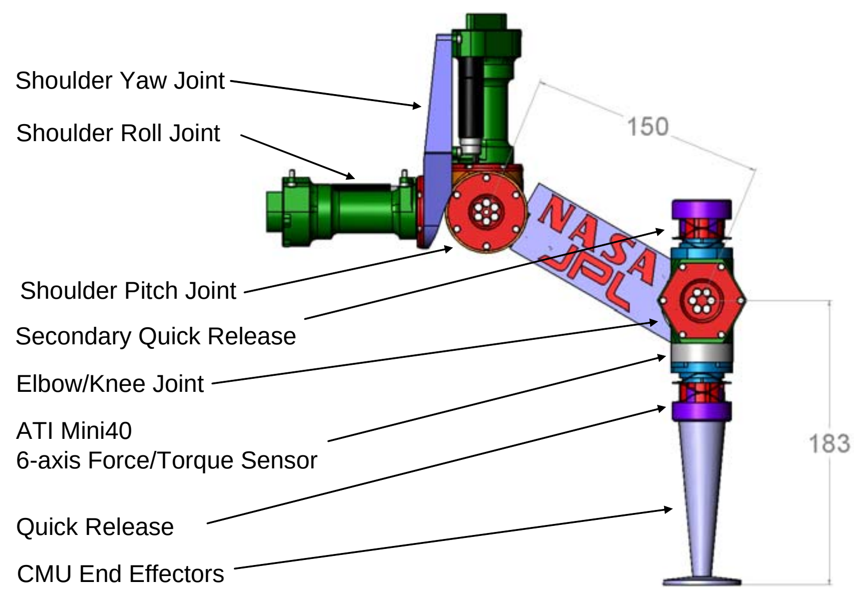


Prototype AWIMR

- **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**





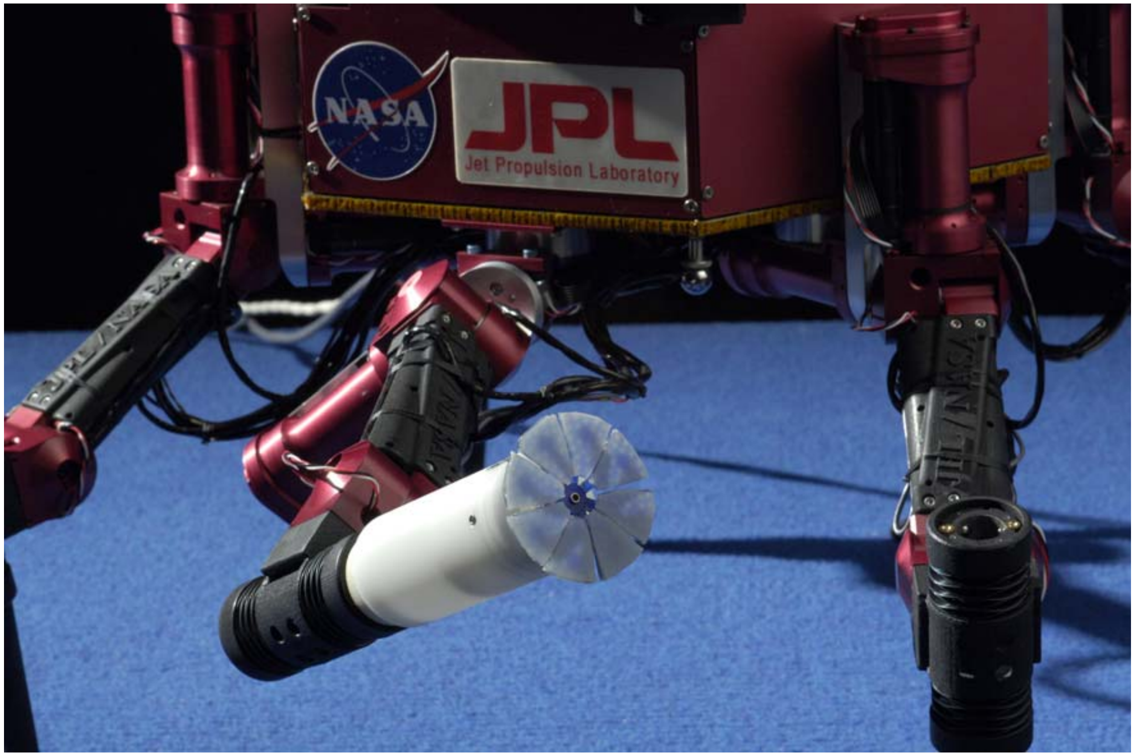


Lessons Learned: Task and Algorithm Iteration

- **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



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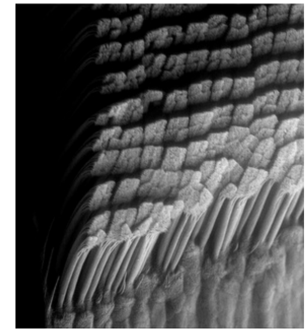
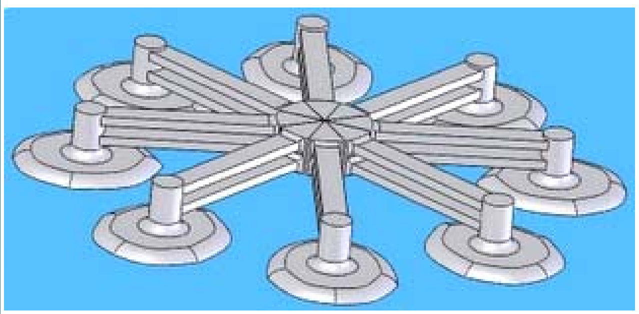
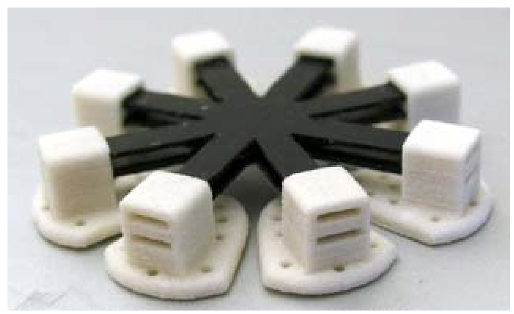
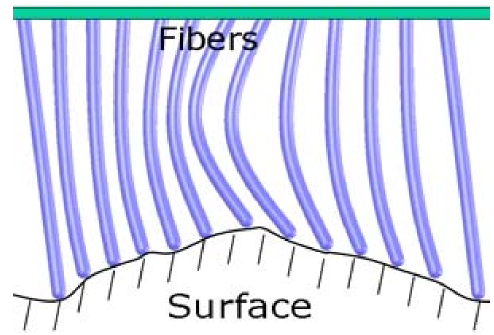
Lessons Learned: Sticky Foot

- 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.

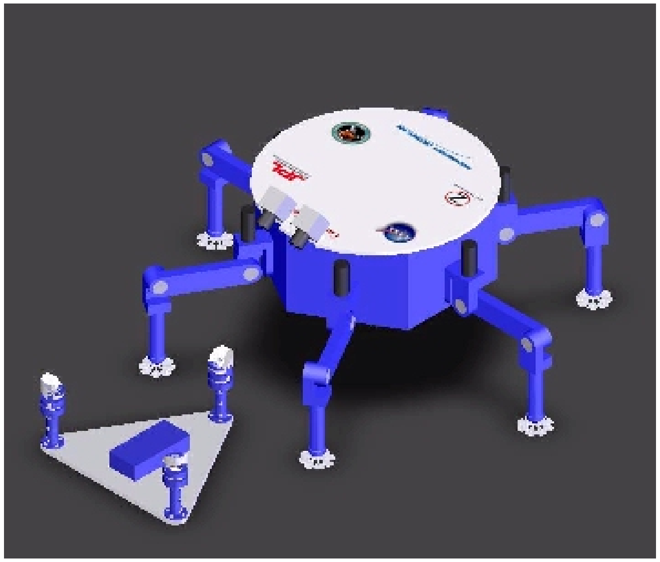
Inspired by the gecko's micro-fiber sticky foot, polymers such as polydimethylsiloxane provide repeatable sticky force greater than preloading force. We found that sticky feet require attention to the zero-g gait.

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



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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