The Design of a Highly Reliable Robot for Unmediated Museum Interaction

Carnegie Mellon University | Robotics Institute
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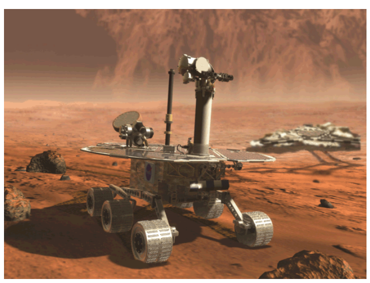
MER Landings, January 2004

Educational goals:

- Rovers as tools for performing science exploration
- The role of rover autonomy during science missions



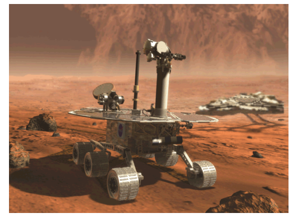
Personal Exploration Rover (PER)

Problem

Connect visitors to the MER mission with an exhibit that demonstrates:

1 Rovers are tools for conducting science

2 Autonomy is essential for collaboration



Approach

Ground-up design of high-reliability museum exhibit

Surmount technology limitations with Intel partnership

Allow for full design and evaluation cycle

Collect data on visitor and docent collaborations with robot

Learning / Science Narrative

The search for life using *organofluorescence*

- Panoramic image acquisition
- Science target selection
- Map correspondence, orientation
- Plan synthesis
- Plan sequencing and monitoring
- Autonomous target approach and measurement
- Report generation

Our Robot Design Approach

- Establish explicit, quantitative goals
- Recruit a multi-disciplinary team
- Create parallel feedback cycles

Our Robot Design Approach

- Establish explicit, quantitative goals
  - Front-end user research to establish needs
  - Clearly defined criteria [+ feed forward ; - feature creep]
  - *Caveat*: Allow for opportunistic changes to goals
- Recruit a multi-disciplinary team
- Create parallel feedback cycles

Our Robot Design Approach

- Establish explicit, quantitative goals
- Recruit a multi-disciplinary team
  - Robotic interaction deserves a systems science approach
  - Expertise beyond robotics: HCI, design, education
- Create parallel feedback cycles

Our Robot Design Approach

- Establish explicit, quantitative goals
- Recruit a multi-disciplinary team
- Create parallel feedback cycles
  - Multiple {design; implement; evaluate; refine} cycles
  - Feed forward results *across* design, EE, HW and firmware efforts

PER: Challenges

Rover Design
System safety & reliability
Panorama acquisition
Simulated MER mechanisms
Science target recognition
Power efficiency

Interaction Design
Un/mediated usability
Limit time on task; throughput
Integrated mission-interface-rover design
Exploit mechanical error to demonstrate autonomy
Compensate for robot/human limitation with human/robot guidance
Translation of panoramic, orthographic, physical yard imagery

Establish Explicit, Quantitative Goals

- Design for robustness
  - 10 hours battery endurance under constant use
  - Unmediated usability by novice users
  - Constant naïve use without degradation
  - In-museum repairability, MTBF > 1 week, MTTR < 1 hour
- Interaction design for museum setting
  - Less than 3 minutes *Time on Task*
  - Completed immersion in narrative (subject to 3 min. constraint)
  - Panoramic image-centered science mission
- Measurable education outcomes:
  - Role of Autonomy; Role of Rovers in Mission Science
  - (Level of comprehension ; comparison of mediated and unmediated exhibits)

Multidisciplinary Team

- Robotics firmware and software
  - Carnegie Mellon Robotics
- Interaction design and testing
  - Carnegie Mellon Robotics
- Embedded electronics
  - Intel Corporation, Botrics Inc.
- Robot hardware realization
  - Gogoco LLC
- Screen and exhibit graphic design
  - LotterShelly LLC
- Educational evaluation
  - Univ. of Pittsburgh Learning Research & Development Center

Project Timeline (8 months)

- May 2003: PER project kickoff
- June: Establish design goals and parameters
- July: Prototype firmware development
- August: Prototype interaction design & test
- September: Interface, firmware programming
- October: Kickoff museum deployments
- November: Software QA
- December: Rover hardware QA
- Jan 04, 2004: MER *Spirit* lands, exhibits launch!

Parallel Design Efforts

Design Goals

Interaction Design | Electronics | Robot H/W | Firmware

Parallel Design Efforts

Design Goals

Interaction Design

Electronics | Robot H/W | Firmware

Personal Exploration Rover (PER)

Deploy PER’s in major national museums
- Visitors and outreach engagement

The search for life using *organofluorescence*
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- Science target selection
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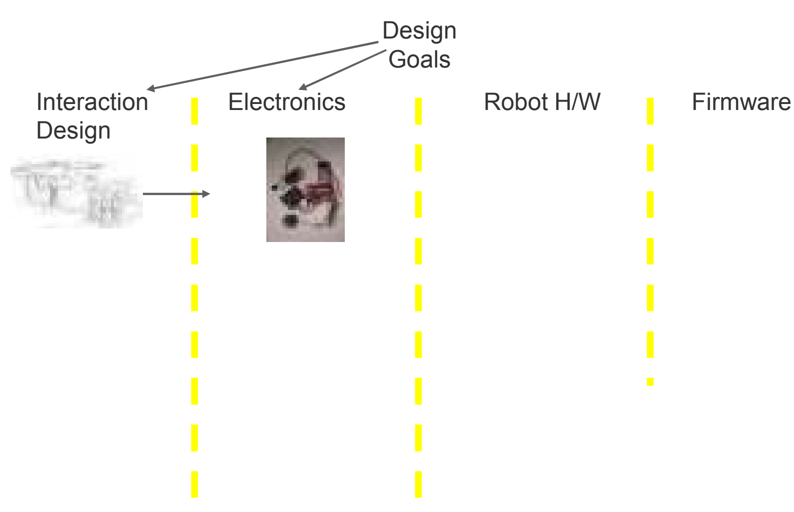
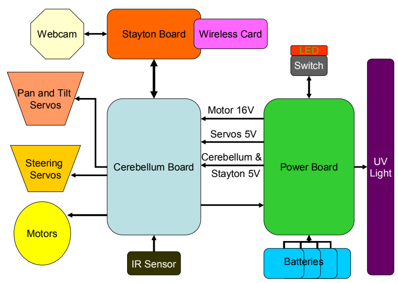
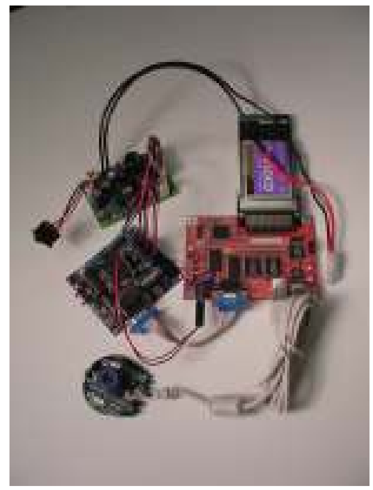
Parallel Design Efforts



Electronics Overview

- Intel Stargate
- Cerebellum PIC board
- Sharp 2Y0A2 rangefinder
- Single switching regulator buses
- 30V unified NiMH power pack





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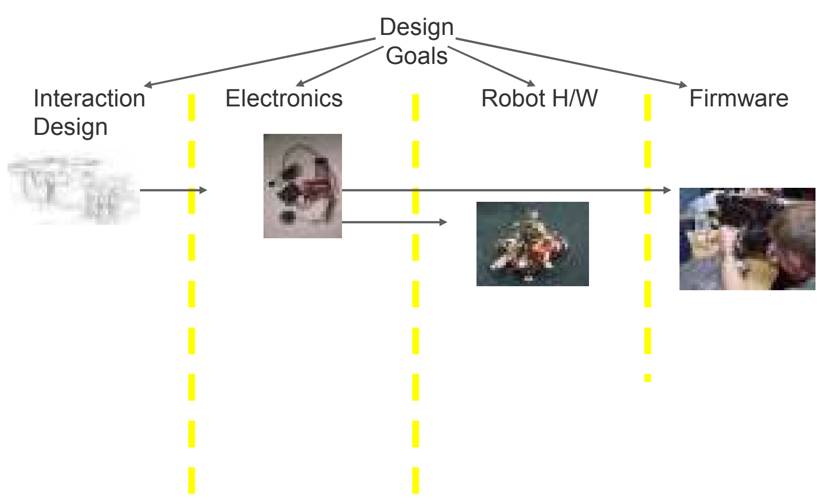
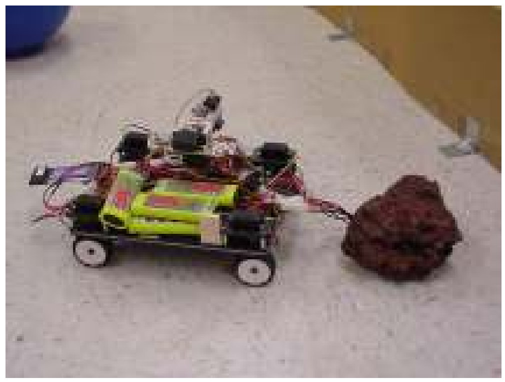


Hardware and Firmware

- Kinematically correct 4-steer simplified chassis for flat-floor evaluation



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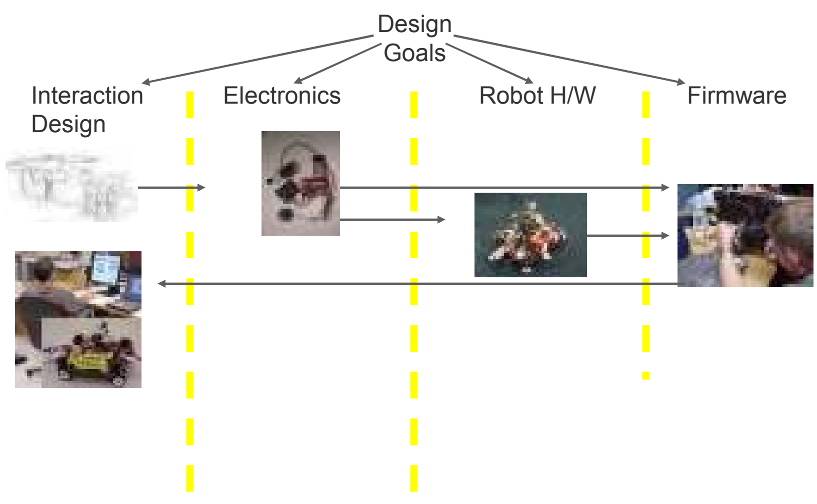
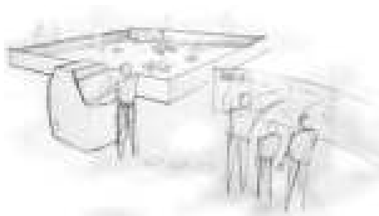


Initial User Studies

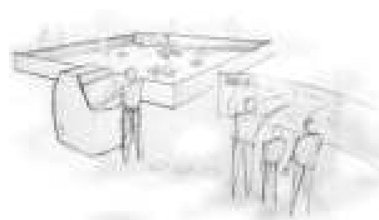
Interaction Design Iterations

- User evaluation using kinematically similar prototype
- Iterative refinement of interface
- 3 minute time on task is hard: key map focus



Interaction Design Iterations

- Exploit mechanical error to demonstrate autonomy
- Compensate for robot/human limitation with human/robot guidance
- Establish translation between panoramic, orthographic and physical yard imagery



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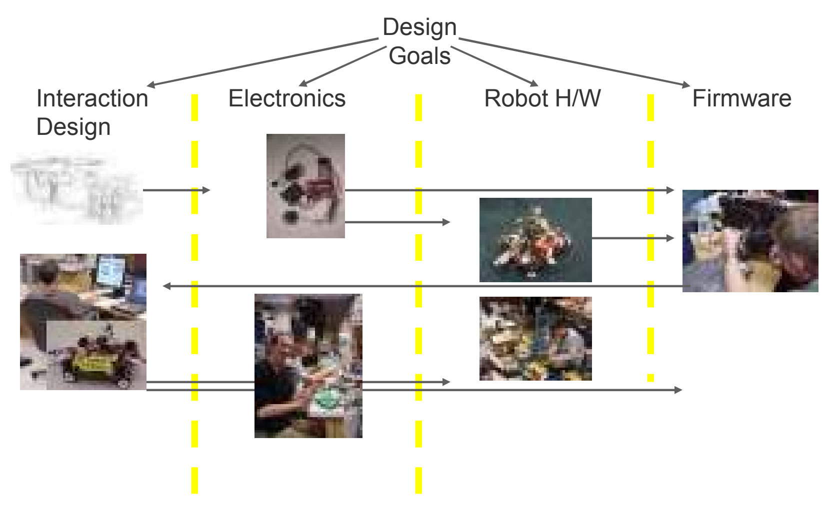
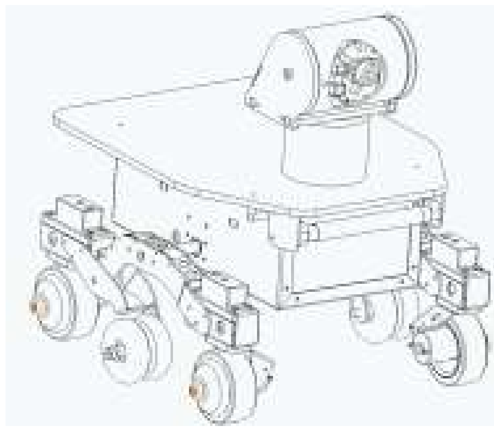


Rover Design



Rover Design

Rover Fabrication

Rover Fabrication

Rover Fabrication

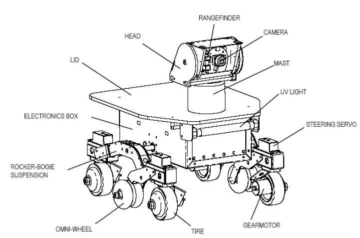
Rover Fabrication

Rover Innovation

Omnidirectional chassis design
Our own production wheel hub
Electromechanical sourcing: Taiwan!
Extreme power efficiency
Panorama acquisition
Obstacle and target rangemapping
On-board Arm core Linux
Twin processor control architecture
Production quantity and QA processes

Mechanical Summary

- MER reminiscent look
- Camera-centered morphology
- Directional gaze design
- UV light, IR sensors
- COTS life-limited parts
- Simplified rocker-bogie



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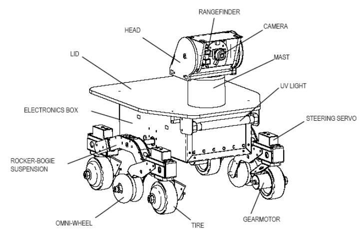

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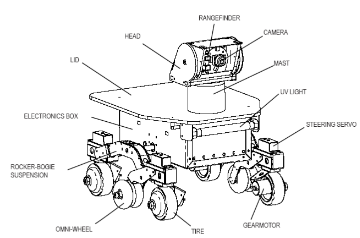

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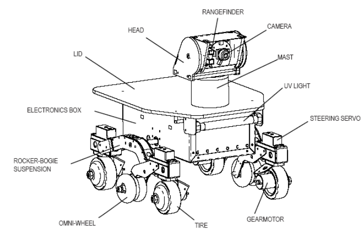

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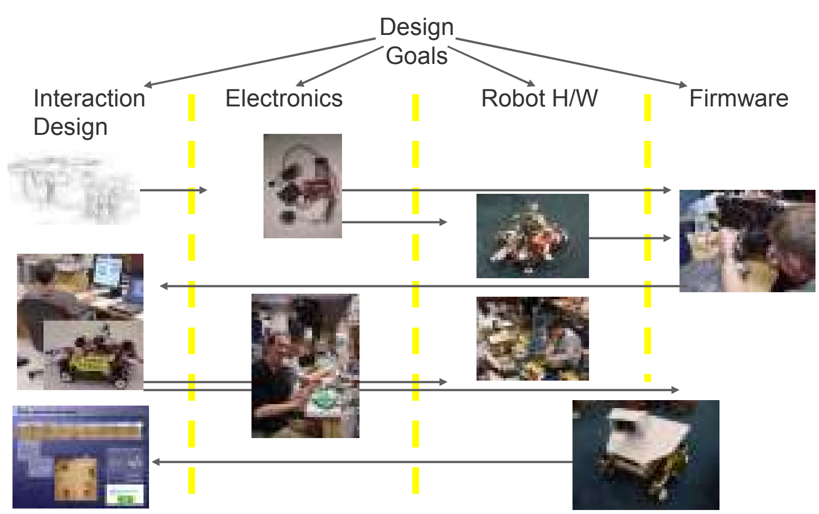


Pick direction and distance
Click on the target rock you want to test for signs of life.
MISSION BUILDER
Direction


Pick direction and distance
MISSION BUILDER
Direction 61°
79-89

In-situ Rover Behavior

National Air & Space Museum

- 15 million visitors per year
- Mars yards built as middle school outreach project
- Topography based on Pathfinder landing site
- Strong collaboration with educational evaluators

National Air & Space Museum

National Air & Space Museum

San Francisco Exploratorium

- Together with NASM, the Big Two
- Joint exhibit, NASM and Explo, is unprecedented
- Twin PER yards separated by full-scale MER model
- Special January “open house” for us

San Francisco Exploratorium

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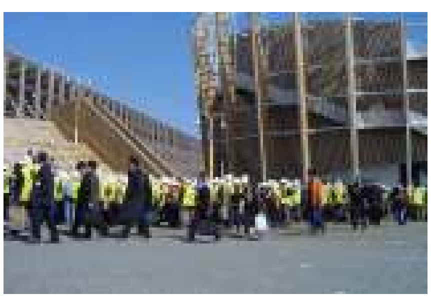
San Francisco Exploratorium

San Francisco Exploratorium

NASA/Ames Mars Center

Japan World Expo 2005 (Aichi)



Project Outcome

- 7 operational rover exhibits over 1 year
- > 5000 rover-hrs, > 100 rover-miles
- More than 100,000 interactions to date
- Cerebellum / Stayton failures: 1
- Full-day battery endurance
- Exploratorium validation of local repair
- Interface statistics
  - Penetration: 98%
  - Mission success: 52%/43%
  - Length: 2.87 m (sig 1.05)
  - Frequency: 1.6 (sig 0.94)

	Before Modifications ~38 operating days/robot for Tilt & Steering Servos ~13 operating days/robot for Motors	After Modifications ~80 operating days/robot for Tilt & Steering Servos ~105 operating days/robot for Motors
Tilt Servos	6	4
Steering Servos	8	16
Motors	5	6

Preliminary Quantitative Results

- Bimodal child/parent age distribution
  Average child's age: 6.75 ; adult: 35.4
- Girls will actuate the interface significantly
  Child driver penetration: 61% boys; 71% girls
  Adult: 26% male; 14% female
- All visitors complete a full cycle of interaction
  Interface penetration is ~ 100%
  Mission length: 2.87 minutes (sigma 1.05)
- Interface countdown is effectively triggering turn-taking
  Number of missions: 1.6 (sigma 0.94)
- Primary use pattern is team-based collaboration
  Mean group size: 3.06 (1.22)
  Gestural and verbal communication frequent

Museum staff interviews

"It's [PER] opening the door for a lot of people on what the future of robotics is and what they can do...It generates a lot of enthusiasm. People are excited by it."

"I expected people to get excited, and for them [PERs] to get attention, but I didn't expect people to get so excited, and for them to get so much attention, for people to like them so much. There's been lines when we're busy, there's been lines at both of the PER's, crowds around the yards, watching what's going on..."

"Unlike most of our exhibits these [PERs] get slammed constantly, opening to closing, with no rest. I think they're holding up surprisingly well. Better than I thought they would."

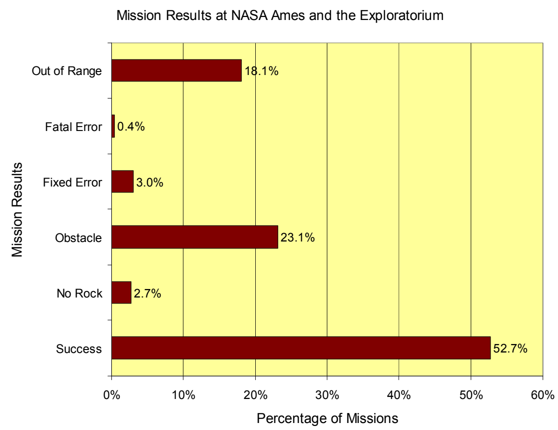
"This exhibit, because it's a 5 minute interaction, it slows people down and gets them thinking about what it's like driving something that's far away, and what are we really looking for on rocks. And I think that's the most important thing in a museum, if you can get people to have their own questions after doing an exhibit..."

Mission Statistics

Six months of automated logging yielded:

- 75.4% active time (331 hours idle from 1017 total hrs)
- 2% of missions timed out (565 / 26,200)
  - Pleasing retention statistic for museum-style exhibit
- User time on task: 4 minutes (sigma 60 sec)
  - Average museum TOT is less than 1.4 minutes
  - 2:20 single mission length (sigma 60 sec)
  - 1.6 missions per user (sigma 0.9)

Mission Summary



Visitors are engaged and able to successfully use exhibit.
Question: Is the exhibit educationally effective?

Learning Evaluation

Question: Is the exhibit educationally effective?

- Socio-cognitive activity of using the exhibit
  - Observation of family conversations at exhibit
  - Particular emphasis on parent talk
- Individual understanding of visitors after usage
  - Open-ended questions to assess impact on explicity learning goals (robots as science tools, role of robot autonomy)

Role of Rovers in Science Missions

Themes	Exploratorium	NASM
About the Mars Mission*	55%	93%
Comparisons between MER and PER*	24%	79%
Communicating with Robots	45%	72%
Collaborating with Robots	86%	93%

- NASM groups significantly more likely to talk about MER and MER – PER comparison
- Parents indicated equal amounts of thematic content at NASA and EXPLO; Docents supply the difference
- 93% - 100% of children demonstrated MER knowledge
- *No statistically significant differences in children's knowledge for categories*

Nature of Rover Autonomy

Themes	Exploratorium	NASM
Rover Design*	34%	93%
Rover Activities*	45%	100%
Rover Autonomy*	52%	93%

- Again, parent thematic content was equivalent, with docent differences
- PER and MER autonomy scores were statistically correlated (p=.001)
- MER autonomy scores were significantly higher at NASM (p=0.035)

Analysis Conclusions

- Two core goals appear to be met strongly
- Family conversation of relevant themes was prevalent
  - Ongoing Mars mission
  - MER and PER comparisons
  - Robot design, technology and autonomy
- Children connected exhibit experience to MER mission in specific ways
- Children continue to have inconsistent views regarding autonomy
  - More than half continue to believe rovers are mostly remote-controlled

Reflections

- Verified robot systems design approach
  - Establish explicit, quantitative goals
  - Recruit a multi-disciplinary team
  - Create parallel feedback cycles
- Robotic technology can and should be utilized for informal learning venues
  - Rapid design and deployment is feasible at relatively low cost (40 robots, $160K)
  - Exploit mechanical uncertainty to demonstrate human/robot collaboration
  - Educational value shows promising impact beyond robotics