

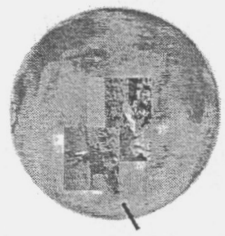


Robotic Exploration of Mars

Multi-Target Single Cycle Instrument Placement

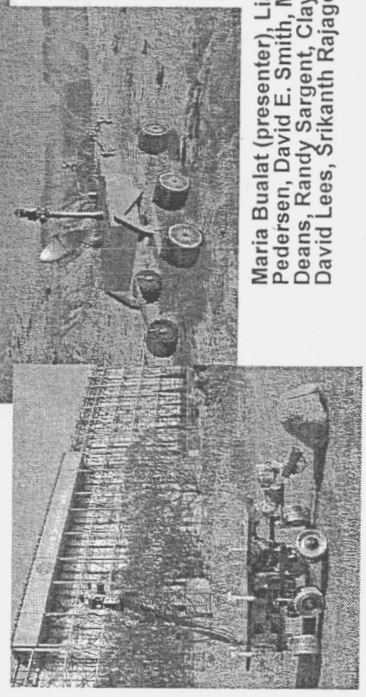
Sojourner

- Max distance from Lander: 12 M
- Total distance traversed 100M
- Time spent waiting: 40-75%
- 2.4 uplinks per science target
- Science cut in half during extended mission



MER

- 3-4 sols for instrument placement on a science target
- 10 sols at each interesting rock
- 240 co-located ground support scientists and engineers for 24/7 operations (primary mission)



Maria Bualat (presenter), Liam Pedersen, David E. Smith, Matthew Deans, Randy Sargent, Clay Kunz, David Lees, Srikanth Rajagopalan

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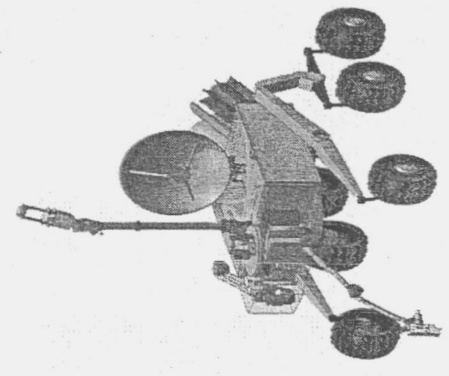
Multi-SCIP Research Goals

Atacama Desert survey showed 0.08% - 0.1% of rocks contain microbial colonies*

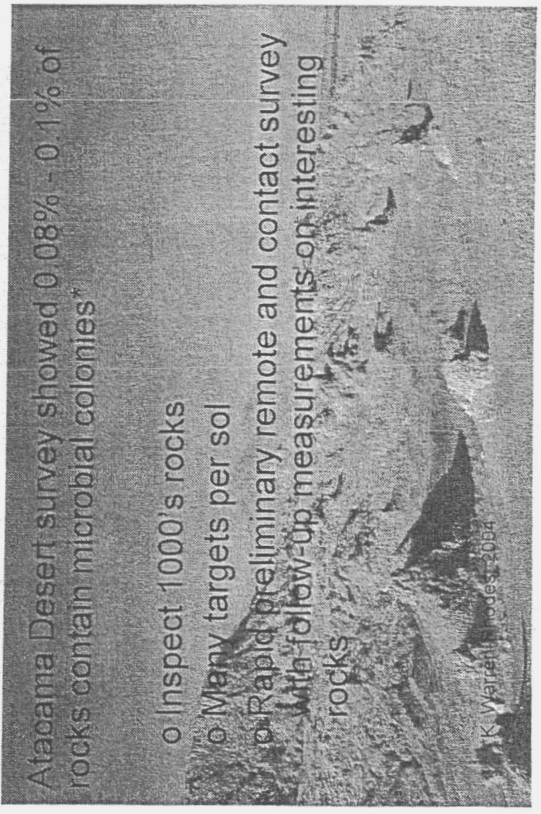
- o Inspect 1000's rocks
- o Many targets per sol
- o Rapid preliminary remote and contact survey with follow-up measurements on interesting rocks

Multi-Target Single Cycle Instrument Placement (Multi-SCIP):

- 10m approach
- 1 cm accuracy
- Multiple targets / command cycle
- Safe operations
 - Safe instrument placements
 - Respect flight rules (e.g., power and time constraints)



Robotic Site Survey



K. Warren, slide 3, 2004

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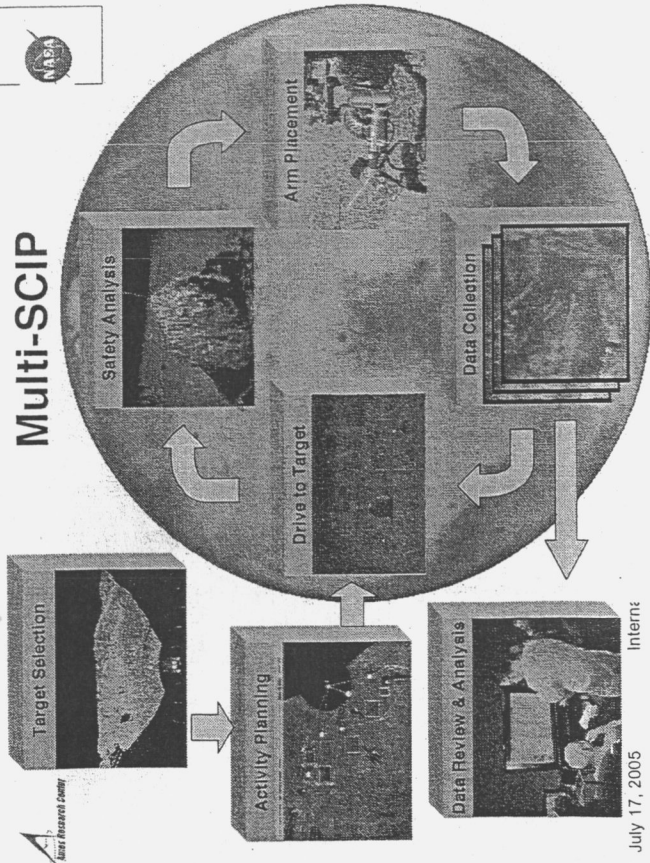
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Multi-SCIP



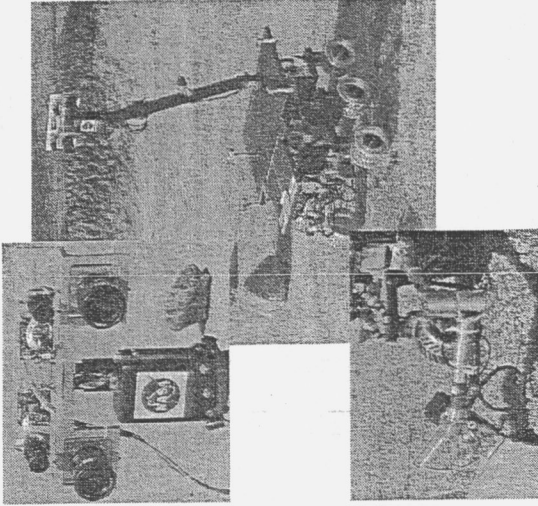
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K9 Rover



- 6 wheel steer rocker-bogey chassis (FIDO, MER)
- 70% MER size
- 1.2 GHz Pentium M laptop running Linux OS
- Odometry and compass/inclinometer
- CLARAty architecture
- 5 DOF manipulator w/ CHAMP microscopic camera
- SciCams, NavCams and HazCams



By Sol N:



- Rover at site
- Image Panorama
- Downlink data
- Data products available for review
- Stereo Model of Environment



Viz

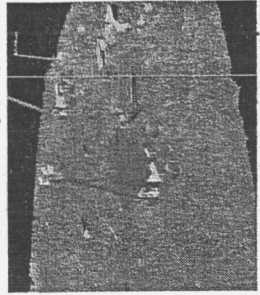
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Observation Requests



- Target point
- Instruments
 - CHAMP microscope
 - Science Cameras
 - (parameters)
- Constraints
 - Time of day
 - Must target be tracked?
- Observation point
 - pose rover must be at to acquire observation (depends on instrument)
- Value of Targets (Utility)

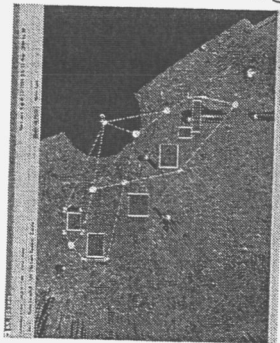


Viz

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Path Generation

- Straight line paths between all pairs of points
- Users indicate obstacle regions as required
- Consolidation of similar paths
- Prune paths most likely to result in tracking failures



PlanView (PathGen)

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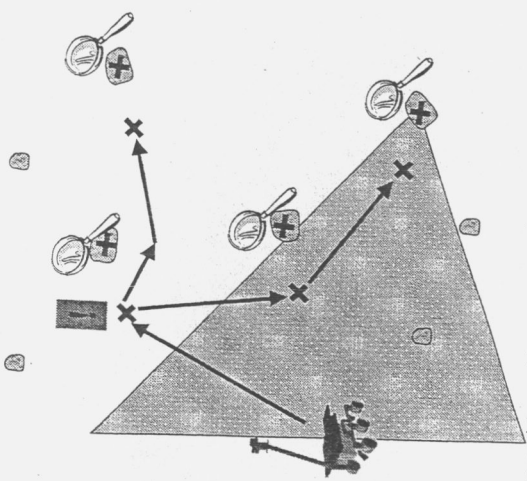
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Off-Board Contingency Planning

Uncertainty everywhere!
Multiple Targets:

- Over-subscription problem – more targets than resources
 - Solve “orienting problem” for goal selection
- Increased chance of losing targets as tracking “constraints” violated.
 - Contingency plans from points where failure is detected.



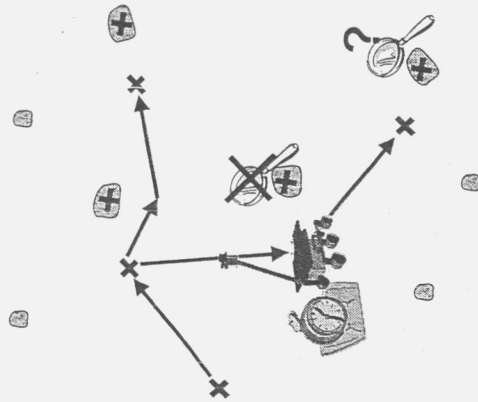
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Contingencies on Resources

- Flight rules impose strict time and energy constraints
- Significant uncertainty in time and energy
- Contingency branches based on resource availability
 - Need to detect impending resource scarcity with sufficient lead time to do something about it



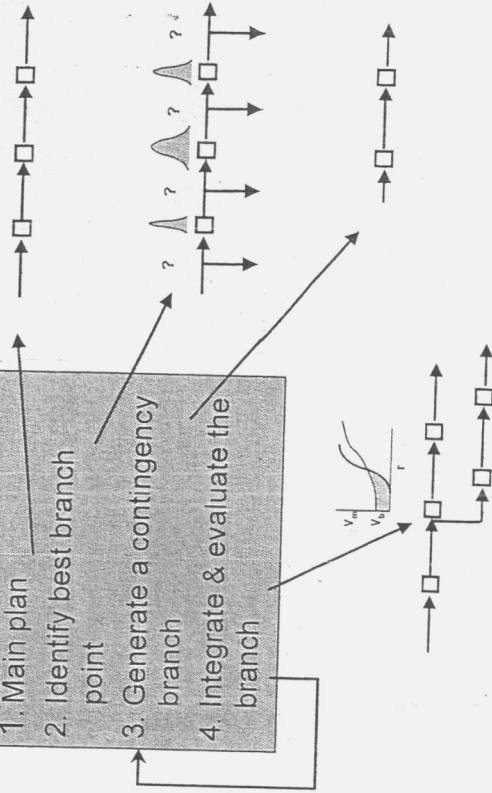
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Contingency Planning Approach

1. Main plan
2. Identify best branch point
3. Generate a contingency branch
4. Integrate & evaluate the branch

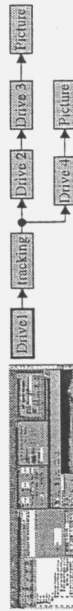
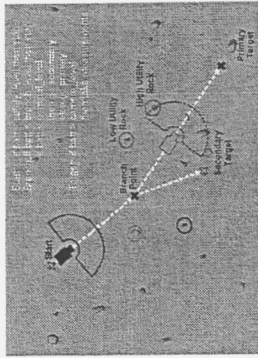


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- Generate sequence
 - Concurrent Contingent Rover Language (C-CRL)
- Execute sequence in simulation
- Iterate planning process until satisfied
- Uplink to rover



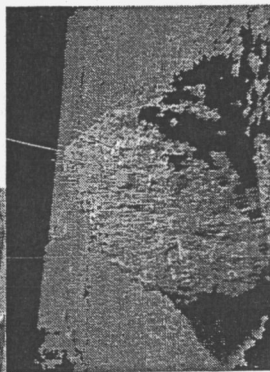
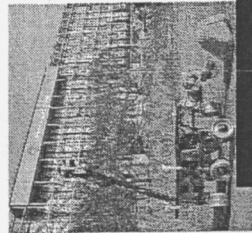
Mission Simulation Facility
CRL Executive

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- Track targets and navigate to them
- At each target in sequence do:
 - Safety check
 - Safe placement on target
 - Acquire science data
- Monitor resources (time, energy) and tracking status
 - Do alternate plans if off nominal
- Uplink science data back to Mission Control

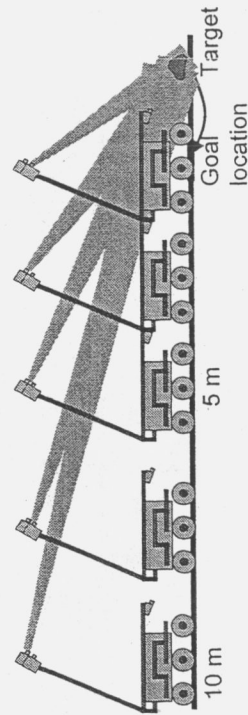


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Multiple targets, 10m distant targets, 1cm precision

- Long (> 20m) traverses
 - Large deduced reckoning error (~10% distance traveled)
 - 2-3 hrs tracking duration
- Large target appearance changes

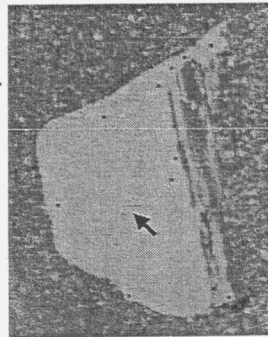


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View from 10m away



View from 1m away



- Target point selected by scientists may not correspond to any visually distinctive features
- Note appearance of texture and rover shadow in close up image
- Note: 10m traverse → 10:1 scale change

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Lighting Changes

View from 10m away



View from 1m away



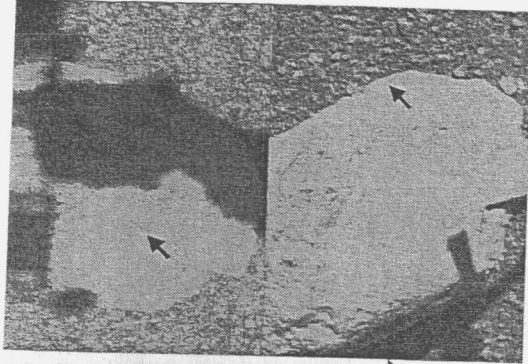
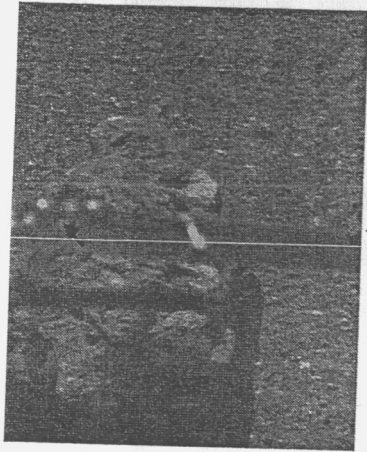
- 10:1 scale change (texture changes)
- Lighting changes
 - Rover shadow
 - Change in position of sun over course of 1-3 hrs sequence execution.

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Occlusions & Orientation Changes



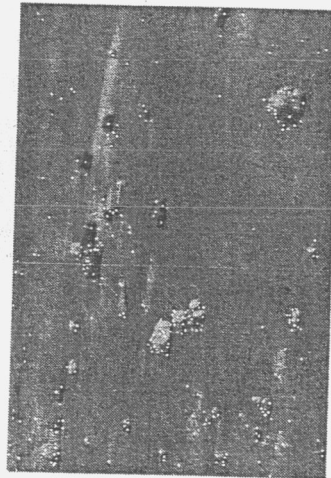
- Occlusion by rover structure.
- Rover positioned such that designated target point is almost completely occluded by the rock-itself

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Approach: 2D Interest Points



SIFT interest operator/descriptor
Fast global matching, no "search"

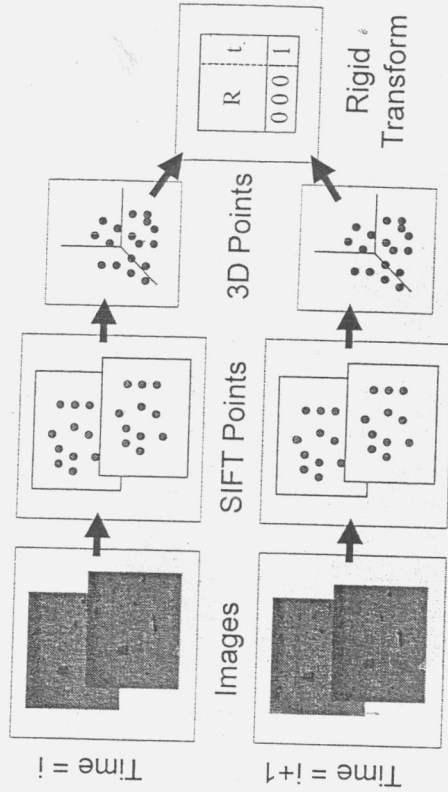
[Lowe, D. G., "Distinctive image features from scale-invariant keypoints," *International Journal of Computer Vision*, submitted June 2003.]

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3D SIFT Target Tracker



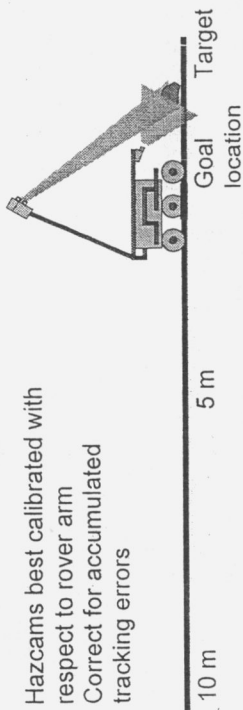
- Integrate motion estimates for each target throughout traverse
- Small increasing tracking error during traverse

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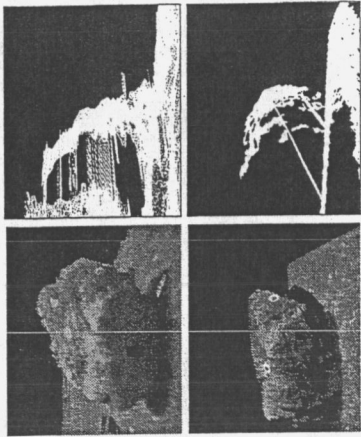
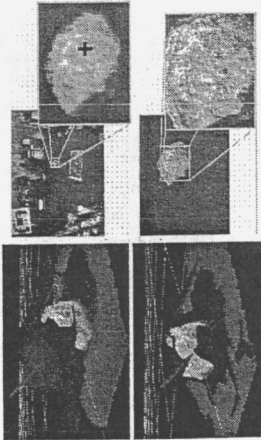
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- Hazcams best calibrated with respect to rover arm
- Correct for accumulated tracking errors

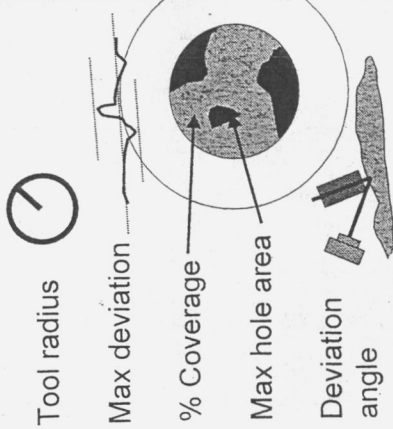
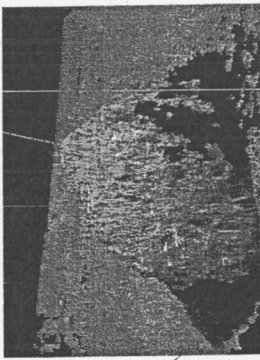


Mesh Registration for Scicam to Hazcam Hand-Off

- Match originally acquired 3D model of target with Hazcam 3D model

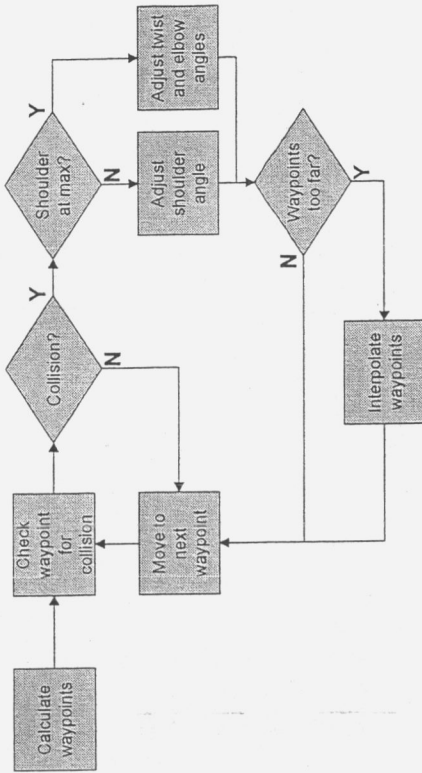


- Cannot guarantee target point chosen from 10m won't damage instrument.
- Potentially large tracking/hand-off error
- Close evaluation of target to confirm presumed target point is safe, and find close alternate if not.

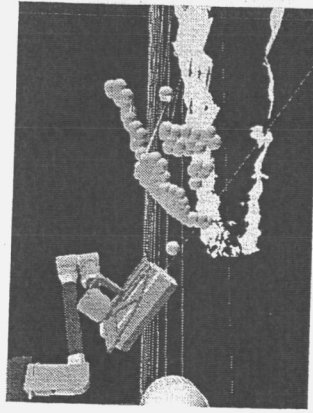


- Safety Check
- Confirm target area will not damage instrument
 - Find nearest safe locations
- Motion Planning
- Confirm reachable and collision free path
- Placement
- Confirm with contact sensors
 - Take measurement

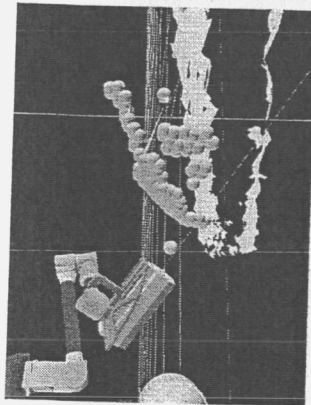
Uses several geometric criteria to ensure safety of instrument Placement location



Arm motion planning



Original waypoints



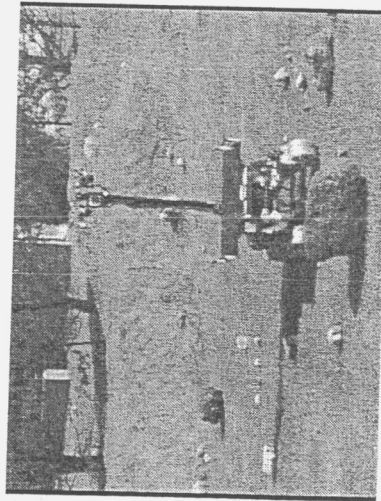
Safe arm motion

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2004 Multi-SCIP Demonstration



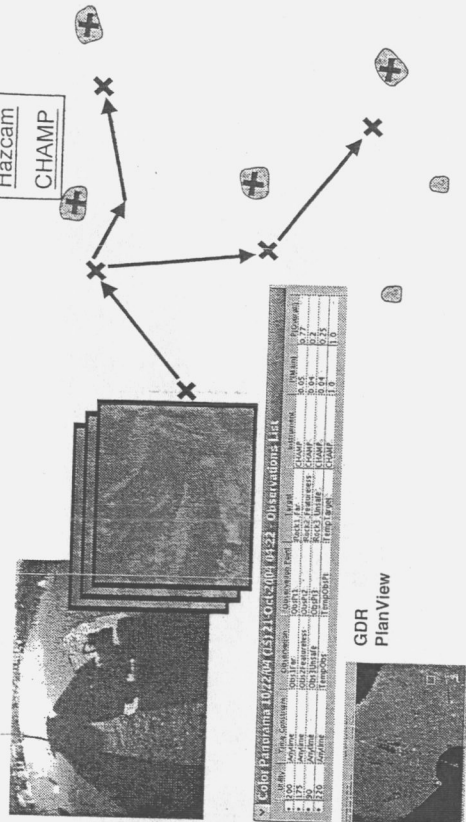
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Data Products & Execution Review

Round Trip Data Tracking



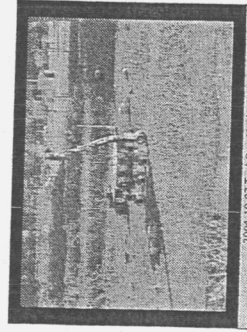
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Accomplishments

- 2004: Multi-Target Single Cycle Instrument Placement
 - 4 targets (1:23 hrs execution)
 - Targets ~ 10m distant
 - Traverse > 10m
 - Up to 1cm accuracy
 - Anticipated fault recovery and resource monitoring
 - Round trip data tracking
- 2003: Single Cycle Instrument Placement
 - Target ~3m distant
 - ~5cm precision
 - Automatic hand-off
 - Opportunistic science
 - ground based contingency planning.
 - Satellite uplink/downlink to rover in Quarry
- 2002: Automated instrument placement on rock



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Acknowledgements

- Intelligent Systems Project
- Astrobiology Science and Technology for Exploring Planets (ASTEP) Program
- Mars Technology Program
 - CLARATy
- NASA ARC Code T/TI
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 - Intelligent Robotics
 - Planning and Scheduling
 - Collaborative Assistant Systems
 - Manipulation Task (JPL)
- Project Management
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 - Srikanth Rajagopalan, PM
- Nav, IP, & K9 Rover
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