Multi-Target Single Cycle Instrument Placement

Robotic Exploration of Mars
- Sojourner
  - Max distance from Lander: 12 M
  - Total distance traversed: 100 M
  - 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
  - 24/7 co-located ground support scientist and engineers for 24/7 operations (primary mission)

Robotic Site Survey
- Atacama Desert survey showed 0.03% - 0.1% of rocks contain microbial colonies
- Inspect 1000's rocks
- Many targets per sol
- Rapid preliminary remote and contact survey with follow-up measurements on interesting rocks

Multi-SCIP Research Goals
- Multi-Target Single Cycle Instrument Placement (Multi-SCIP):
  - 10 m approach
  - 1 cm accuracy
  - Multiple targets / command cycle
  - Safe operations
    - Safe instrument placements
    - Respect flight rules (e.g., power and time constraints)
Multi-SCIP

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

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)
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

Off-Board Contingency Planning

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

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

Contingency Planning Approach

1. Main plan
2. Identify best branch point
3. Generate a contingency branch
4. Integrate & evaluate the branch
Plan Review and Sequence Generation

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

Sequence Execution

- 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

Visual Target Tracking

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

Featureless Targets, Scale Changes & Shadows

- 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
Lighting Changes

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

Occlusions & Orientation Changes

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

Approach: 2D Interest Points

SIFT interest operator(descriptor)
Fast global matching, no "search"


3D SIFT Target Tracker

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

- 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

Safe Placement

- 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.

Instrument Placement Safety Evaluation

- Tool radius
- Max deviation
- % Coverage
- Max hole area
- Deviation angle

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

Arm motion planning

- Calculate waypoints
- Check waypoint for collision
- Move to next waypoint
- Adjust shoulder, elbow
- Adjust twist angles
- Interpolate waypoints
- Waypoint too far?
- Shoulder at max?

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Arm motion planning

Original waypoints

Safe arm motion

Data Products & Execution Review

Round Trip Data Tracking

GDR PlanView

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2004 Multi-SCIP Demonstration

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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