Human Robot Site Survey
2007 Haughton Crater Field Test

haughton2007.arc.nasa.gov

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Human-Robot Site Survey Project

Systematic survey

- Civil engineering survey, geophysical study, resource prospecting, etc.
- Systematic, detailed coverage (necessary to ground-truth remote sensing)
- Unproductive for crew to perform manually (repetitive, tedious, time-consuming)

Haughton Crater Field Test

10 July – 3 August 2007

- Two ARC K10 planetary rovers with survey instruments
  - 3D scanning lidar for topographic mapping
  - Ground-penetrating radar (GPR) for resource prospecting
- Test robotic survey systems and operational procedures
- Multiple lunar analog sites at Haughton Crater (Canada)

Haughton Crater
(Devon Island, Canada)
Field Test Location

Haughton-Mars Project (marsonearth.org)
Shackleton Crater at the South Pole of the Moon is 19 km in diameter and might present H₂O ice in surrounding shadowed zones. It is a prime candidate site for human exploration. Haughton Crater, also ~ 20 km in size, is by far the best preserved impact structure of its class on Earth and is located in a H₂O ground ice–rich rocky desert. Haughton may be the best overall scientific and operational analog for lunar craters such as Shackleton.
Field Test Conditions

Weather (July)
- Winter in the high desert
- 0 to 15 deg C
- Mostly dry (some precipitation)
- Windy: 0 to 35 kt
- Mostly clear (clouds at 500 ft)

Environment
- Daylight 24/7
- Very, very dusty
- No vegetation
- Broad mixture of terrain
Survey Locations
“Drill Hill” Survey

Survey plan

- K10 robot on-site for 3 days
- HMMWV simulates pressurized rover (temporary habitat)
- Resource prospecting: subsurface ground-penetrating radar scans (parallel transects with 50 m spacing)
“Drill Hill” Survey

Survey plan (parallel transects with 50 m spacing)

K10 robot path (real-time display on Google Earth)
Survey Equipment

K10 rover (3rd generation)
- 4-wheel drive, 4-wheel steer
- Split rocker chassis
- Size: 1.3 x 0.9 x 1.0 m (HxWxL) with sensor mast
- Speed: 0.9 m/s (on 10 deg slope)
- Power: 1900 W (Li-ion batteries)
- Weight: 100 kg (including 25 kg payload)
- dGPS, stereo cameras, compass, 2D laser scanner

Optech ILRIS-3D (topographic mapping)
- Scanning 3D lidar with 40 deg FOV
- Range: 3 to 1,500 m
- Range accuracy: 7 mm @ 100 m

JPL CRUX GPR (subsurface mapping)
- Ground-penetrating radar
- 800 MHz center frequency
- 15 cm resolution to 5 m depth
K10’s at Haughton

![Image of K10's at Haughton with measurements: 1.3 m, 1 m, and 0.9 m.]
Access Routes

Equipment (CA ANG)

Field team (commercial air)
Haughton Field Team
Field test equipment

- Two K10 robots, "FieldOps" gear, "HabOps" computers, spares, etc.
- 3,500 lbs. shipped from ARC (via C-130 and Twin Otter)
- Haughton-Mars Project: base camp, generators, satellite voice/data link
Approaching Haughton Crater

“Fortress”

“Tent City”

HMP Base Camp

600 m
HMP Base Camp
HMP Lodging

“Tent City”
K10’s at Haughton

GPR survey

3D lidar survey
K10 Lidar Survey
K10 Lidar Survey
K10 GPR Survey
K10 GPR Survey
Site Survey Dataflow

Orbital images

3D Modeling

Coverage Planning

Survey Plan

Robotic Survey

Data Product Generation

Terrain analysis

Coarse DEM (LROC equiv)

Traversability Map

3D Modeling

Coverage Planning

Survey Plan

Data Product Generation

Terrain analysis

Coarse DEM (LROC equiv)

3D Modeling

Coverage Planning

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3D Modeling

Coverage Planning

Survey Plan

Data Product Generation

Terrain analysis

Coarse DEM (LROC equiv)
Coverage Planning

3D lidar
- Choose locations for taking panoramic scans
- Uniform sample spacing
- Google Earth + off-line planner

Ground-penetrating radar
- Choose path for GPR scanning
- Line transect survey
- Grid-based “path transform” (Zelinsky et al. 1993)
3D Terrain Modeling

3D model of Ames Marscape from multiple lidar scans
Terrain Pipeline Dataflow

**Terrain Generation**
- DEM / texture tiles

**Terrain Database**
- tiled multi-res DEM

**Terrain Server**
- DEM request plug-in
- JDBC
- DEM / texture tiles

**Application**
- WMS-compliant client
- HTTP (OGC WMS)

- Stereo imagers, 2D/3D lidar, etc.
- Stereo correlation
- Point cloud surface fitting
- Iterative Closest Point alignment
- Image/feature based correspondence
- Incremental update & source data
- Terrain patch creation
- DEM output conversion (e.g., image)
- JPEG 2000 + meta-data
- Viz 3D UI, Google Earth, etc.
3D Terrain Modeling

K10 Red lidar survey

“Fortress” formation near HMP base camp
3D Terrain Modeling

“Fortress” formation (DEM from lidar scans)
3D Terrain Modeling

1m polar grid

elevation map
3D Terrain Modeling

HMP base camp (1 m polar grid)
3D Terrain Modeling

Valley mapping (1 m polar grid)
Remote Operations

ARC Intelligent Robotics Group
Remote Operations
NASA
NASA JSC

"Lunar Outpost" "Mobile Habitat"

ARC JSC
Ground Ops
IVA Ops

ARC
NASA ARC

JSC
NASA JSC

"Lunar Outpost"
"Mobile Habitat"

Handout Image 1: Remote Operations - ARC Intelligent Robotics Group
IVA Ops ("Lunar Outpost")
IVA Ops ("Mobile Habitat")
Ground Ops (JSC Code ER “Cockpit”)
Ground Ops (JSC Code ER “Cockpit”)

Viz Explorer (K10 Black)

Viz Explorer (K10 Red)

Google Earth
Ground Ops (ARC)

- Viz Explorer
- Google Earth
- 3D terrain model
Viz Explorer

- interactive 3D views
- status messages
- camera view
Lidar Survey Displays

- 3D terrain
- HMP base camp
- survey points
- heading estimates
- local traversability map
- K10 rover shadow
GPR Survey Displays

- GPR data (vertical)
- transect lines
- 1x1 meter grid

ARC Intelligent Robotics Group
HMP Base Camp Survey (20 July 2007)

HMP base camp near greenhouse
Google Earth

Satellite image overlay

Von Braun Planitia
HMP Base Camp - Test City
Drill Hill
Haughton Crater

ARC Intelligent Robotics Group
HMP Base Camp Survey (20 July 2007)

- GPR survey (K10 Black)
- Lidar survey (K10 Red)
- HMP Base Camp
- K10 location
- "Tent City"
Drill Hill Survey (23-27 July 2007)

Survey plan (green)

Survey boundary (blue)

K10 path (black)
2007 Phase 1 SBIR (X7.02)

• Support system health & performance monitoring
• Monitor data for problems (robots or instrumentation)
• Perform computations summarizing daily progress
• Notify users of alarms, alerts and reports based on roles
• Distribute reports (web or email)

PI: Debbie Schreckenghost (Traclabs, Inc.)
Auto-Summarization & Notification

Telemetry logs

- Condition Monitoring
  - Computation
  - Summary Generation

- Summary Report

- Notification
  - Scientist Agent
    - Display Email
  - Rover Operator Agent
    - Display Email
  - Field Coord Agent
    - Display Email
  - Data Analyst Agent
    - Email
  - Research Coord Agent
    - Email
Robotic survey

- 200+ hours of rover operations (incl. 10 hours out of comm range)
- 46.2 km of driving (K10 Red + Black)
- 25 lidar panoramas (250 scans)
- 30 GB of survey data
Cost (field-test only)

- 6 people field team
- 25 days (10 July – 3 August 2007)

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Transport (personnel)</td>
<td>$29,384</td>
<td>Commercial air (SFO - HMP)</td>
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<tr>
<td>Transport (equipment)</td>
<td>$13,942</td>
<td>3,500 lbs (via ANG + Twin Otter)</td>
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<tr>
<td>Lodging + ME&amp;I</td>
<td>$32,572</td>
<td>21 days at Haughton, 4 travel days</td>
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<tr>
<td>Contracts</td>
<td>$119,279</td>
<td>HMP support, satellite comm, field transport, fuel, etc.</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$195,178</strong></td>
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Lessons Learned

Operations
- Dense coverage requires long distance driving
- Continuous navigation is a key enabler for long-duration, long-distance driving
- Instrument constraints have a huge impact on systems operations

Visualization tools
- Essential for rapid contingency handling & high duty-cycle
- Provide awareness of robot status & perception
- Unified science & robot data facilitates situational awareness

Software Architecture
- Modular reconfigurable architecture enabled rapid instrument integration and field test adaptations
- COTS tools greatly facilitated development
  - Google Earth: geo-spatial display & public outreach
  - CORBA: robust comm performance across satellite links
Conclusion

Key Points

• Systematic survey is one task that should be performed by robots
  ▪ Robotic surveying is realistic & achievable (TRL 5)
  ▪ Unproductive for crew to have to perform manually
• Intermittent control is sufficient for IVA & ground operations
• Mission performance can be increased by off-loading utility tasks (routine, tedious, repetitive) to robots
Project Team