Over-Snow Rovers for Polar Science Campaigns

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Why Polar Robots?

• Harsh & remote = high cost to conduct field science
• Extend spatial & temporal coverage
  — Repetitive (boring), systematic surveys
  — Atmospheric science, glaciology, geology, space weather, extreme biology
• Improve safety of crevasse detection for traverses
Yeti & Cool Robot

Lightweight, reliable, efficient
- 4WD (firm snow) – low drivetrain losses
- GPS waypoint following
- Zero emissions (batteries, solar)
- ~ 160 kg towed-payload capacity
- 3 – 7 km/hr survey speeds

Student design projects
- Mission: to support polar science & operations
Yeti – Autonomous GPR Surveys

- Greenland inland traverse crevasse zone (2008, 2012)
- South Pole traverse crevasse zone (2009, 2010)
- Old Pole station – buried buildings (2011)
- Mt Erebus ice caves (2012)
- McMurdo-Ross Ice Shelf shear zone (2013 – 15)
# Yeti Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design Target</th>
<th>Measured Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rover mass (kg)</td>
<td>70</td>
<td>81</td>
</tr>
<tr>
<td>Payload mass, towed (kg)</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Dimensions (m)</td>
<td>1.1 x 1.0 x 0.6</td>
<td>1.1 x 1.1 x 0.9</td>
</tr>
<tr>
<td>Speed (m/s): maximum</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>: average</td>
<td>1.5</td>
<td>1.1 – 1.8</td>
</tr>
<tr>
<td>Duration (h)</td>
<td>2</td>
<td>2.2 – 9.3</td>
</tr>
<tr>
<td>Range (km)</td>
<td>10</td>
<td>12 – 34</td>
</tr>
<tr>
<td>Path-following tolerance (m)</td>
<td>± 5</td>
<td>± 3</td>
</tr>
<tr>
<td>Minimum temperature (°C)</td>
<td>-30</td>
<td>-32</td>
</tr>
<tr>
<td>Wheel diameter (m)</td>
<td>0.51</td>
<td>0.51</td>
</tr>
<tr>
<td>Ground clearance</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Ground pressure (kPa)</td>
<td>&lt; 35</td>
<td>20</td>
</tr>
<tr>
<td>Housekeeping power (W)</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>Resistance per unit weight, R/W</td>
<td>0.25</td>
<td>0.08 – 0.31</td>
</tr>
</tbody>
</table>

\[
P_b = P_h + \frac{W(R/W)V}{\eta_{mg}}
\]

\[
\sim 500 \text{ W, batteries 1,200 Whr}
\]
South Pole Traverse Route

- Shear-zone boundary between Ross & McMurdo ice shelves
GPR Crevasse Detection

- Radar returns continuously scroll across screen
- Crevasse signature varies with snow conditions & approach angle
- 2 – 4 sec to stop vehicle
- 8 – 12 hr/day focused on GPR screen
- Survey is on critical path for traverse schedule
- High stress & tedious (boring)
Sensitivity to Approach Angle
Autonomous vs Manual GPR

- Increased safety, reduced stress
- Continuous GPR records across hazards
- Adds capability
  - Increased search area
  - Regular, gridded surveys
  - Rosette pattern to investigate “unknowns”
- Developing auto-detection
  - Classify: yes, no, maybe
  - Run auto-rosette if maybe
  - Auto-detect will help manual surveys too
Greenland Inland Traverse Route

- Complex crevasse fields through transition onto ice cap
Yeti 2012 Survey

- 34 km of survey lines, 97% auto
- ± 3 m GPS precision
- Demonstrated various survey patterns, including rosettes
- High reliability, good mobility
- Immobilized in basin of soft snow
- Two tip-overs in tractor ruts
Old Pole Survey

- 1950’s station buried under ~ 30 ft of snow
- Tractor fell into access hatch in 2009
- Manual GPR survey, blasting in 2010
- *Yeti* survey Dec 2011 after winter infilling
Results

- 10 km of auto surveys
- No immobilizations, -33° C
- Good navigation
  - S 89.987 to 89.988
- Off-continent GPR review
- Found another hazard
Systematic Survey

- 10 crossings in 2 directions, continuous records
- Increased confidence & defined extent
- “Metal-roof building 3 – 4 m below surface”
Future Work

- Tilt limit
- Pre-immobilization detection (M. Eng thesis)
- Autonomous crevasse detection (PhD thesis)
- Auto mapping of crevasse locations

- GPR survey of Ross-McMurdo shear-zone
  - Oct 2013
  - boundary condition on Ross Ice Shelf (stability)
  - 5 km x 5 km grid, 63 m line spacing
  - repeat 2014, 2015
Cool Robot

Summer deployments
• Solar power (24 hrs, renewable, zero emissions)
• Moderate temperatures (-40 C)
• 3 km/hr survey speed = 500 km/week

Simple = Reliable, Efficient & Low Cost
• 4WD, 60 kg, 15 kPa (2 psi) on tires
• GPS navigation (no vision system)

Student design, fabrication & testing
• 6 M.Eng., 4 B.Eng.
Cool Robot Capabilities

- 60 kg, 1.2 x 1.2 x 1 m
- 20 kg payload (40 kg sled)
- 500 km in 2 weeks (0.4 m/s), max. 1 m/s
- Payload power: 15 W driving, 200 W stationary
- Twin Otter transport without disassembly
- Autonomous GPS navigation
- *Iridium* satellite communications
- Tailor for specific polar science missions
Unique Solar Design

- Passive solar avoids sun tracking
- Vertical panels good at polar elevations
- Brilliant snow reflects sunlight onto panels
- Sufficient power for 500 km/week
- Control system matches power input with demand

270 W electrical power @ 20° sun elev.
35% is reflected power

Top 19% (direct)
Back 8% (refl. only)
Front 59% (direct + refl.)
Sides 20% (refl. only)

- ~ 300 W-hr deficit balanced by batteries

Power In (W)

Hour of Day

Power Budget 80S
Solar In = Power Needed
Validated power-budget model, power control & navigation

- Power match to 16° sun elevation (4 panels, low clouds)
- Then max power point tracking
- Successful navigation 5 – 8 hrs (minor algorithm errors)
- Soft snow: R/W = 0.21, Pt = 220 W at 0.8 m/s
Long Mission Concerns

**Sastrugi**
- Common 10 – 30 cm on 1 – 3 m scales
  - Effect power consumption, control & navigation
- Chart routes around large sastrugi

**Winds**
- Tip-over > 20 m/s
- Tradeoff solar area for lower profile
- Move every hour during blizzards

**Crevasses**
- Drive over bridged crevasses
- Chart routes around open crevasses
Future Work

• New solar box (lighter, better access, higher efficiency)
• Microprocessor, GPS same as Yeti

• Long-endurance science demo Summit June 2013
  — circumnavigate station for several days, ~ 300 km
  — sample emissions footprint (J. Dibb)
  — radar profile snow stratigraphy (M. Albert)


Questions?