Real-Time Robotic Surveying for Unexplored Arctic Terrain

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Motivation

Objective

➢ To make more information available to remote-sensing systems using autonomous or semi-autonomous robotic solutions.

➢ Specifically, provide higher-resolution shape and slope characteristics of terrain than currently offered.

Strategy

➢ Intelligently collect changes in terrain using robotic technology.
Motivation

- The limitation of the pixel footprint…

Example L7 Landsat ETM+ (Band 8) Image*

*Image acquired from Google Images
Motivation: EOS

- An Earth Observing System needs:
  - Satellite capable of orbiting the earth
  - Multiband, high-powered radiometer (spectroradiometer)
  - Complex signal processing algorithms for imaging

- Available resources:
  - Multiple scene perspectives
    - Globally (ex situ): Landsat, ICESat, MODIS
    - Locally (in situ): Automatic Weather Stations (AWS), human field campaigns, aerial fly-bys
Motivation: In situ tools

- We have several options for in situ data collection.
  - Automatic Weather Stations
    - Coverage
  - Aerial campaigns
    - Cost
  - Human field campaigns
    - Safety
- Robotic alternative
  - Mobile
  - Cheap
  - Expendable

*Images acquired from Google Images*
Motivation: Augmentation

Satellite Instrumentation (MODIS, ETM+, AVHRR, ASTER) → Pre-filtering

Current in situ measurement methods (AWS, Aerial, Human) + Autonomous in situ SnoMote Navigation → Calibration of Measurements

User Information Request (i.e., Pixel footprint specification) → Image filtering & processing → Hi-Resolution Imagery
Surveying: History

- Multitude of survey types
  - Land, Route, City/Municipal, **topographic**, construction, hydrographic, mining, forestry…
  - Topographic surveys “are made for locating objects & measuring the relief, roughness, or three-dimensional variations of the Earth’s surface.” (Surveying, 2nd ed., J. C. McCormac)

- Traditional requirements
  - 2 – 3 person team: Observer, Rodman, Eyeman (optional)
  - Distance measuring equipment (i.e. EDM, GPS, tape measure, levels, leveling rod)
  - Multiple elevation measurements
Surveying: Currently

- Few explicit limitations exist, but there is a balance between equipment and man power.
- Total Stations cost between $7K and $40k depending on available features and age.
- AutoCAD (w/ Civil3D package), and Land Development are used to generate contour maps based on imported data from surveyors.
Surveying

Defining in’s and out’s of surveying

- Contacted surveyor companies to interview about modern surveying methods
  - Boundary Zone Inc.
- Key issues: Measurement location selection and curvature
- Control Point Vs Checkerboard Method
- Curvature is defined via estimating contours
  - Less control points $\leftrightarrow$ Less information available
- More information is better…even if the customer (i.e. scientist) doesn’t realize it…
Additional theoretical work was done by others including R. R. Hashemi (U. Arkansas) and E. Tunstel (APL, Johns Hopkins U.)

Originally developed ideas for locating items in a 2D search space (i.e. water, Martian gases, etc.)

Focus on maximizing Quality of Performance, QoP = (A_s / D_s)

**Single Agent**

Strip Approach

- Strip Approach
- Tube Approach

**Dual Agent**

Improved Strip Approach

- Improved Strip Approach
- Relaxed Improved Strip Approach
Emphasis of previous work is on which navigation pattern minimizes distance over an area, A.

Here, a single-agent executing a “lawnmower” pattern achieves the highest QoP, yet these patterns can be adjusted to suit the application.

Image acquired from Tunstel, et al., *Rover Prototype for Mobile Surveying Technology Development*, NSBE ASC 2010

June 22\textsuperscript{nd}, 2010

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Surveying: Robotics

- Previous work has included applications for...
  - Pseudo-Martian planetary exploration (via simulated environments)
  - Agricultural and farming products

While useful, their mission objectives varied, none of which included terrain characterization.

Approach

- Combine **land surveying principles** and **coverage algorithms** to create a robotic survey system.
Claim: If surveyors base control point selection on changes in terrain elevation, robots should do the same, but do so more intelligently.

Presume we know...

- A measurement of the maximum height and minimum depth of a terrain.
- We only survey areas exhibiting a range of angular orientations.
  \[ \theta_{\text{min}} < \text{Pitch}_{\text{Terra}} < \theta_{\text{max}} \]
  \[ \phi_{\text{min}} < \text{Roll}_{\text{Terra}} < \phi_{\text{max}} \]
- GPS is available so as to assign sensed information with a sufficiently known location.

Problems that this research can address:

- Obtaining a more accurate measurement of curvature.
- Developing a specific approach to increase information gain in lieu of manually increasing the number of measurements.
Approach

Consider an arbitrary terrain

Navigate intelligently to sample terrain

Approximate the result

Insert re-generated terrain HERE

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Approach

- DemMaker in MATLAB
  - Useful for simulating desired “pixel” size (~250x250 m² areas).
  - Both “roughness” as well as specific terrain aberrations can be simulated (i.e. hills or craters).
  - Maps are easily imported into 3D Gazebo world environment.
Approach

- Computer graphics
- Physics-based approach to surface reconstruction using multiple finite element methods.

Figure 5: (a) Original digital terrain map. (b) Rendered contour data. (c) Reconstructed terrain.

Images acquired from http://www.scs.ryerson.ca/~tmcinern/

June 22nd, 2010

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Example Application

- Field tests in Piedmont Park, Atlanta, GA
- Area Under Test was selected
  - 20 [m] x 40 [m]
  - Low undulating terrain
  - Obstacle-free
  - Elevation reference of 880 [ft]
  - Steadily increasing slope
Example Application

- 2D contour comparison
  - Taking contours of the regenerated data, then visually compared to the online map data shows a close comparison of 12-14 [ft] in elevation differential from the reference.

- Results presented at AIAA Infotech@Aerospace 2010, Atlanta, GA.

0.2 [m] resolution
1 [m] resolution
2 [m] resolution

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Example Application

- 3D Terrain Regeneration
  - Following filtering and post-processing, we recreated the AUT at 1[m] and 2[m] resolutions.
Example Application

- Albedo measurement...

Cloud-free surface Reflectances → Atmospheric correction → Black/White Sky Albedos

RossThicke-LiSparse BRDF Model → Nadir BRDF adjusted surface reflections (NBAR)

BRDF Model Parameters: $(f_{iso}, f_{vol}, f_{geo})$

$R = (f_{iso}) + (f_{vol} * K_{vol}) + (f_{geo} * K_{geo})$

Courtesy of Crystal Schaaf (http://www-modis.bu.edu/brdf/userguide/intro.html)

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Example Application

Albedo measurement...

Cloud-free surface Reflectances → Atmospheric correction

RossThicke-LiSparse BRDF Model

In situ data from robotic solution

Black/White Sky Albedos

Nadir BRDF adjusted surface reflections (NBAR)

BRDF Model Parameters $(f_{iso}, f_{vol}, f_{geo})$

$R = (f_{iso}) + (f_{vol} \cdot K_{vol}) + (f_{geo} \cdot K_{geo})$

Courtesy of Crystal Schaaf (http://www-modis.bu.edu/brdf/userguide/intro.html)
SnoMote Project

- Previous arctic robotics projects involve developing a single large expensive robot.
  - CoolRobot (Dartmouth)
  - Nomad (CMU)
  - MARVIN (U. of Kansas)
- Multi-agent systems require the development of potentially dozens of agents.
  - Inexpensive design
  - Consumer-grade sensing
  - Agent loss is tolerated
- Agents must still have significant terrain traversing capabilities.
SnoMote Project

- Servo motor
- Weather sensors
- Compass
- GPS
- WiFi
- DC motor controller
- Camera
- Gumstix Processor

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SnoMote Project

- The SnoMotes
  - Inspired by a snowmobile design.
  - Includes on-board sensors (vision, humidity, temperature, pressure, and tilt) and real-time processing.
  - Field-tested in Juneau, AK on Mendenhall and Lemon Creek glaciers in June 2009.
Observations: Decadal Survey

- Relevant projects
  - Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI)
    - To record the response of ice sheets to climate change.
  - Gravity Recovery and Climate Experiment (GRACE-II)
    - Spatio-temporal fluctuations of the Earth’s mass distribution.
  - Ice, Cloud, and land Elevation Satellite (ICESat-II)
    - Altimetry measurements to determine the contribution of terrestrial ice cover to global sea levels.

- All benefit from increased bandwidth of information afforded by robotic technology.
Observations

Aim

- Not to replace current capabilities, but to augment them.
- Increase knowledge base of scientific information currently available.
- Improve efficiency and safety of earth scientists.

Image acquired from Tunstel, et al., *Rover Prototype for Mobile Surveying Technology Development*, NSBE ASC 2010
References

- Center for Remote Sensing, Boston University
- Website: [http://www-modis.bu.edu/brdf/product.html](http://www-modis.bu.edu/brdf/product.html)
- PPT: MODIS BRDF/Albedo Products from Terra and Aqua, BU, Dept. of Geography


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Questions?