A Survey of Techniques for Detecting Layers in Polar Radar Imagery

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Introduction

• The Problem

• Understanding Layers in the radar images:
  the ice thickness and accumulation rate maps help studies relating to the ice sheets, their volume, and how they contribute to climate change.

• Develop an semi-automated and automated tools for tracing Layers in radar imagery
RADAR Imagery

• A radar trace consist of signals, representing energy due to time.

• In an image, a trace is an entire column of pixels, each pixel represents a depth.

• Each row corresponds to a depth and time for a measurement, as the depth increases further down.
Challenges in Processing RADAR Imagery

- **Bedrock/Surface Layers**
  - Two Layers (but, false positives)
  - Low magnitude, faint, or non-existent bedrock reflections
  - Strong surface reflections can be repeated in an image causing surface multiples

- **Near Surface Internal Layers**
  - Multiple Layers (a couple dozen)
  - Fuse into existing Layers
  - Disappear and Reappear
Bedrock (Hidden Markov Model)

Active Contours

- Active contour models, computer generated curves, which move within images to detect object boundaries
- Used in Image Segmentation
- Examples
  - Level Sets, Intelligent Scissors, Snakes
Level Sets

• A level set is defined by a set of points, where a function is constant (the boundary is zero):

\[ \Gamma = \{(x, y) \mid \phi(t, x, y) = 0\} \]

• The level set evolves in a direction normal to a gradient, which is determined by a PDE in order to minimize the cost function

\[ g(I) = \frac{1}{(1 + |\nabla G_\sigma * I|)^2} \]
Bedrock (Level Set)

Bedrock: Level Sets vs. Hidden Markov Model

<table>
<thead>
<tr>
<th>Approach</th>
<th>Bedrock ME</th>
<th>Bedrock MSE</th>
<th>Surface ME</th>
<th>Surface MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level Set</td>
<td>7.1</td>
<td>342.0</td>
<td>4.1</td>
<td>31.8</td>
</tr>
<tr>
<td>Hidden Markov Model</td>
<td>37.5</td>
<td>11700.0</td>
<td>14.6</td>
<td>490.3</td>
</tr>
</tbody>
</table>

We performed 5 and 3.5 times better, on average, than the hidden markov model for tracing bedrock and surface layers, respectively.
Bedrock Approaches...

• Active Contours (“Snakes”)
  Automated Polar Ice Thickness Estimation From Polar Radar Imagery
  Christopher Gifford, Gladys Finyom, Michael Jefferson, MyAsia Reid, Eric Akers, and Arvin Agah

• Statistical Map Generation and Segmentation
  A Technique for the Automatic Estimation of Ice Sheet Thickness and Bedrock Properties from Radar Sounder Data Acquired at Antarctica
  Ana-Maria Illsei, Adamo Ferro and Bruzzone
Snakes

- A snake is defined in the \((x,y)\) plane of an image as a parametric curve

\[ v(s) = (x(s), y(s)), s \in [0,1] \]

- A contour has an energy \((E_{\text{snake}})\), which is defined as the sum of the three energy terms.

\[ E_{\text{snake}} = \int (\alpha E_{\text{elastic}}(v(s)) + \beta E_{\text{bending}}(v(s)) + \gamma E_{\text{image}}(v(s))) ds \]

- Detecting Layers reduces to an energy minimization problem.
Near Surface Internal Layers

Internal Layer Approaches...

• Cross-correlation and a Peak following routine
Internal Layer Tracing and Age Depth Accumulation Relationships for the Northern Greenland Ice Sheet
  M. Fahnestock, W. Abdalati, S. Luo, and S. Gogineni

• Ramp based function
Tracing the Depth of the Holocene Ice in North Greenland from Radio-Echo Sounding Data
  Nanna B. Karlsson, Dorthe Dahl-Jensen, S. Prasad Gogineni, and John D. Paden

• ARESP 6 Phases
Automated Processing to Derive Dip Angles of Englacial Radar Reflectors in Ice Sheets
  Louise C. Sime, Richard C.A. Hindmarsh, Hugh Corr
SNOW RADAR DERIVED SURFACE ELEVATIONS AND SNOW DEPTHS MULTI-YEAR TIME SERIES OVER GREENLAND SEA-ICE DURING ICE BRIDGE CAMPAIGNS

Dragana Perkovic-Martin, Michael P. Johnson, Benjamin Holt, Ben Panzer, Carl Leuschen

Method:
Support Vector Machine Training/Testing

Results:
56.08% of the 430,000 measurements were determined to be tracked
Other Techniques for Detecting Layers...

- Finding, following, and linking edge fragments to construct curve corresponding to either one or more image feature
  

- Pyramid-based edge detection for identifying image objects and lines
  

- Image texture used as a descriptor for segmenting images into constituent parts or identifying image regions
  

Conclusion

• Identified representation of estimating layers in
  • Bedrock and Surface
  • Internal Layers
  • Interface Layers (air/snow, snow/ice)
• Discussed techniques, which can aid in solving the Layer problem
Discussion/Questions?