Automated Polar Ice Thickness Estimation from Radar Imagery

MyAsia A. Reid[1], Michael Jefferson[1], Eric L. Akers[1], Gladys Finyom[2], Christopher M. Gifford[3], and Arvin Agah[3]

[1]Mathematics and Computer Science Department, Elizabeth City State University, Elizabeth City, NC 27909
[2]University of Arizona, Tucson, Arizona, 85721
[3]Center for Remote Sensing of Ice Sheets, University of Kansas, Lawrence, KS 66045

ABSTRACT

This work focuses on automating the tedious task of estimating ice thickness from airborne radar data acquired over Greenland and Antarctica. The process involves the identification and accurate selection of the ice sheet's surface location and interface between the ice sheet and underlying bedrock for each measurement. Each measurement, typically called a radar trace, consists of a signal representing received energy over time, where larger time corresponds to deeper reflections. In an image, a trace is an entire column of pixels, with each pixel representing a uniform depth. Each image row corresponds to a depth in ice (and time) for the measurements, with depth increasing further down the image. A flight segment is a collection of traces representing all columns of the image, from the beginning of the segment (left side of the image) to the end of the segment (right side of the image) during flight. Automated extraction of higher level information, such as ice thickness, has seen limited application to ice sheet and Polar subsurface data. Most efforts involve manual or guided identification or tracing of specific layers that hold historical importance. Internal layers of ice sheets have been investigated to predict the depth and thickness of certain layers. For example, initial efforts to predict the depth and thickness of the Eemian Layer in the Greenland ice sheet utilized a Monte Carlo Inversion of the flow model to estimate unknown parameters constrained by the internal layers [1][2].

Knowing the surface and bedrock locations in the radar imagery enables the computation of ice sheet thickness, which is important for the study of sheets, their volume, and how they may contribute to climate change issues. The previous time-consuming manual approach requires sparse hand selection of surface and bedrock interfaces by several human experts, and interpolating between selections to save time. Two primary methods have been studied: edge-based, and active contour. In the edge-based approach, edge detection, thresholding, and edge following are utilized to identify the layers of interest for ice thickness estimation. The concept behind this approach is that the surface should be the maximum value in each trace, and that the bedrock reflection layer should be the deepest contiguous layer in the image. Edge detection and thresholding can be used to identify strong edges in the image, which can be further used to locate and follow the layer corresponding to the bottom of the ice sheet. Similar work has been done, in which a skyline detector was implemented by descending down each column and marking pixels as part of the sky until a threshold is exceeded [3].

In the minimalist active contour approach, an initial contour is adaptively manipulated and evaluated using image and contour property costs. Motivation for this approach stems from the method utilized onboard the Mars Exploration Rovers (MER) for automatic sky segmentation – via skyline identification – in imagery acquired on the surface of Mars

[4][5]. In that approach, an active contour consisting of one particle per column, initially located at the top of the image, is pushed downward until it reaches the horizon. The contour arrives at an equilibrium state via the combination of three “forces”:

(1) gravity-like force which pushes the contour downward,
(2) upward force based on image edges providing buoyancy, and
(3) tension force between neighboring particles using the assumption that the horizon’s slope does not exceed 45 degrees.

Once the contour is fit to the horizon, the sky can be segmented for further analysis of cloud content (weak layering in the sky). Our approach uses a similar active contour/snake technique to fit a contour to the bottom layer using image and contour costs and a gradient force which pushes the contour upward from the bottom of the image. The contour’s shape is adaptively modified and evaluated to minimize path cost or energy through the image to match an image feature, sometimes used for segmenting an image into its cohesive regions. Such approaches have been used in medical imagery (such as MRIs and CAT scans) [16], tracking curves in clutter [14], boundary detection and image segmentation [17]. Results are compared and presented in terms of time requirements, error, and advantages which each method offers. Automatic ice thickness estimation results from 2006 and 2007 Greenland field campaigns show that the edged-based approach offers faster processing (seconds compared to minutes), but suffers from a lack of continuity and smoothness aspects that active contours provide. The active contour approach is more accurate when compared to ground truth selections from human experts, and has proven to be more robust to image artifacts. Figure 1 show results from both methods for comparison. Figure 2 shows the human expert selections together with both automated methods for the 20060527b (B) flight segment. Each method essentially selects the same surface interface location for the entire file. A zoomed portion of the bedrock is also shown. This allows a direct visual comparison of each method’s results, including their differences in certain situations. These figures illustrate where the methods differ and provide examples of situations where they fail to accurately select the bedrock interface. Typically, the edge method is successful for strong contiguous edges in the image, but fails if the bedrock reflection is weak. It also fails when there are artifacts beneath the bedrock. Although faster, this method lacks global continuity and smoothness aspects, which prevents the selection of fully connected contours in some of the images.

The automated ice thickness estimation technique is now being used by researchers to expedite data processing to release the radar data for public and scientific use. Both methods are available and configurable. Current results are significantly speeding up processing of the data. Some radar files, however, are nearly impossible to automatically estimate ice thickness. These challenging files still require human attention. Any image areas that are not adequately identified can be quickly cleaned up by a correction tool that has been developed, in which the user can view the selections, outline those selections to fix, and correct them via interpolation, semi-automated selection using a simple maximum difference method, or manual selection. Users, if time and care are taken to properly complete the task, are superior in terms of being able to quickly determine how to logically bridge gaps in the bedrock reflection and follow faint reflections through heavy noise. This, however, consumes time and human attention that would be more fruitfully used for other efforts.

This research is a first effort in the goal of fully automated radar image processing and understanding. The described approaches can be advanced for higher level understanding of radar images for science purposes. For example, it is envisioned that using similar automatic processing methods onboard autonomous systems, such as ground or aerial vehicles, can help guide the platform toward areas with specific subsurface characteristics (deep bedrock layer, weak bedrock return, etc.). Furthermore, it can aid in the automatic calibration of the radar's settings for optimal subsurface return intensities using the bedrock return as an optimization parameter during flight. Similar methods as those presented in this paper may also be useful for subsurface layer finding/following and segmentation applications for various other mediums. The finding/following, and linking edge fragments are used to construct a connected curve corresponding to one or more salient image features [6]. As subsurface imagery extends further from Earth's surface (high altitude UAVs, space-borne satellites and radar systems, or extending to other planets), automatic characterization such as ice thickness estimation over Greenland and Antarctica ice sheets will be imperative to maximize data processing quality and autonomous science return.

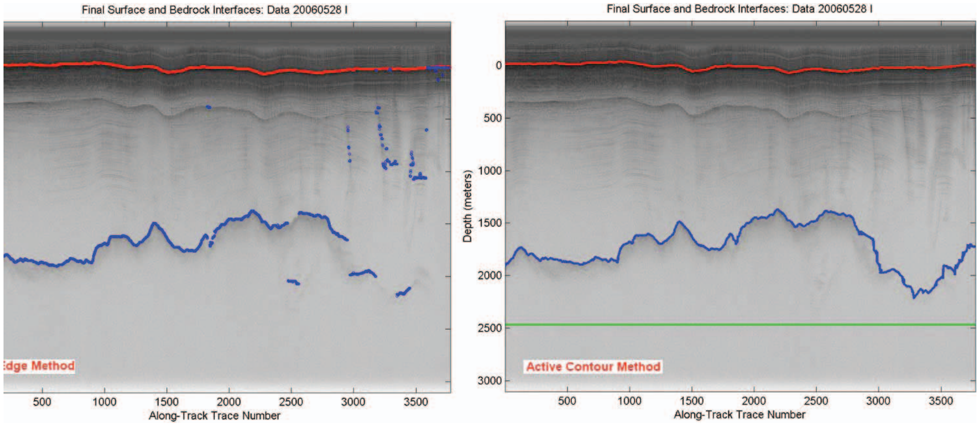

Fig. 1. Comparative results for flight segment 20050528(I). The edge-based method (left) again has difficulty with faint bedrock reflections (e.g., traces 3000, 3250, 3500-3750), but also selects an artifact (e.g., trace 2500) below the bedrock as part of the interface layer. The active contour method (right), due to stiffness and continuity aspects, is able to accurately follow the layer across the faint areas and avoid the artifact.

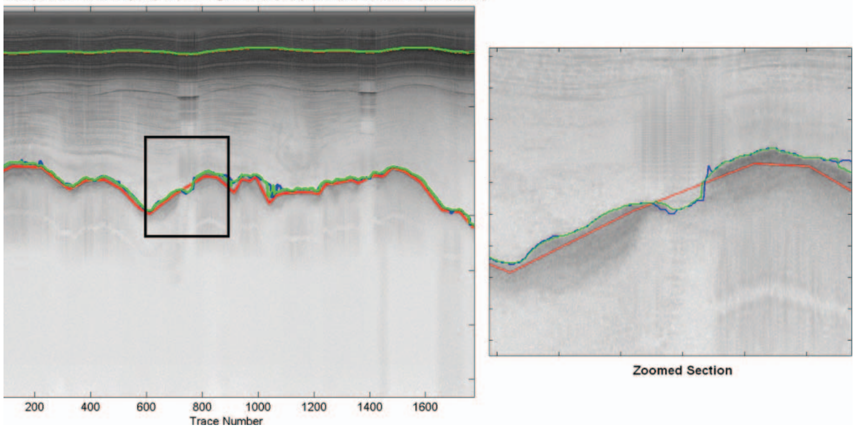

Fig. 2. Comparison of human expert, edge-based method, and active contour method selections for the 20060527b(B) flight segment. A zoomed portion of the echogram is displayed for a finer resolution comparative analysis, illustrating the differences between each method for certain situations.

BIBLIOGRAPHY

[1] S. L. Buchardt and D. Dahl-Jensen, “Estimating the Basal Melt Rate at NorthGRIP using a Monte Carlo Technique,” Annals of Glaciology, vol. 45, no. 1, pp. 137–142, October 2007.

[2] S. L. Buchardt and D. Dahl-Jensen, “Predicting the Depth and Thickness of the Eemian Layer at NEEM Using a Flow Model and Internal Layers,” in Geofysikdag, 2007.

[3] F. Cozman, E. Krotkov, and C. Guestrin, “Outdoor Visual Position Estimation for Planetary Rovers,” Autonomous Robots, vol. 9, no. 2, pp. 135–150, 2000.

[4] V. Gulick, R. Morris, M. Ruzon, and T. Roush, “Autonomous Image Analysis during the 1999 Marsokhod Rover Field Test,” Journal of Geophysics Research - Planets, vol. 106, no. E4, pp. 7745–7764, 2000.

[5] T. Roush, M. Shipman, R. Morris, P. Gazis, and L. Pedersen, “Essential Autonomous Science Inference in Rovers (EASIR),” in Proceedings of the IEEE Aerospace Conference, vol. 2, Big Sky, MT, 2004, pp. 790–800.

[6] M. Isard and A. Blake, “Condensation - Conditional Density Propagation for Visual Tracking,” International Journal of Computer Vision, vol. 29, no. 1, pp. 5–28, 1998.

[7] J. Kratky and J. Kybic, “Three-Dimensional Segmentation of Bones from CT and MRI using Fast Level Sets,” in Medical Imaging: Proceedings of the SPIE, vol. 6914, 2008, pp. 691 447–691 447–10.

[8] W. Ma and B. S. Manjunath, “EdgeFlow: A Technique for Boundary Detection and Image Segmentation,” IEEE Transactions on Image Processing, vol. 9, no. 8, pp. 1375–1388, August 2000.

[9] R. Czerwinski, D. Jones, and W. O’Brien, Jr., “Line and Boundary Detection in Speckle Images,” IEEE Transactions on Image Processing, vol. 17, no. 12, pp. 1700–1714, December 1998.