Grid Search Optimization on Viterbi Algorithm for Ice Bottom Detection

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Abstract

The Center for Remote Sensing of Ice Sheets (CReSIS) collects radar imagery of ice sheet bottom topography in regions such as Antarctica and Greenland, to help scientists and engineers understand the role of polar ice sheets in sea level change. An essential task in our long term study of this imagery is to locate the position of the bedrock beneath the ice sheet. However, since we add a large volume of imagery data each year, to manually label the position of the ice bottom is very time consuming. Thus, advanced computer algorithms, such as the Viterbi algorithm*, have been employed to automatically track the bed-rock locations [1]. The objective in our project is to tune the Viterbi algorithm parameters to improve the accuracy of detecting the ice bottom location, as compared to manually tracked data.

Problem Formulation

Why do we collect the ice topography imagery, and how do we collect it?

It is useful to have precise Ice-bed topographic imagery to study glaciers and ice streams. For example, ice velocity is roughly proportional to the fourth power of ice thickness [2], and bed and surface geometry can be used to determine the hydraulic potential and consequently, subglacial hydraulic pathways [3]. As the Intergovernmental Panel on Climate Change (IPCC) reports that models used to generate sea-level rise estimate do not include the dynamic processes being observed in Greenland and Antarctica in 2014, our data helps modelling the contribution of polar ice sheets to sea level.

Multiple airborne ice thickness surveys have been undertaken since 1970. More than 344,000 line kilometers of airborne data were collected, with a majority of them having been collected since the year 2000 [5]. Aircraft equipped with ground-penetrating radar devices such as the Multichannel Coherent Radar Depth Sounder (MCoRDS) [5] , map the underground structural information of the ice (Fig. 1). By applying a series of signal processing techniques to the collected data, we can generate images such that we can distinguish the interface between air and ice (ice-surface), and the interface between ice and bed-rock (ice-bottom) along the flight profile.

We produce two kinds of imagery of the ice surface and bottom –3D imagery (Fig. 3), composed of a sequence of cross-track images, and 2D or profile imagery (Fig. 2) which show just a vertical cross-section through the ice. Once the imagery is generated, the task at hand is to use these images to determine the locations of the interfaces, so that the ice-sheet thickness can be quantified.

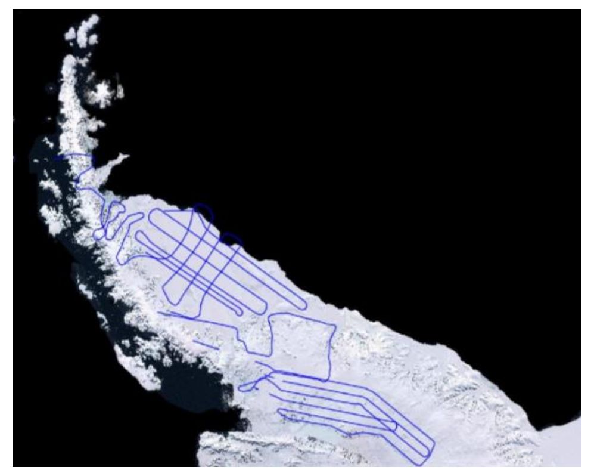

Fig.1 Satellite image with the flight path used for data collection

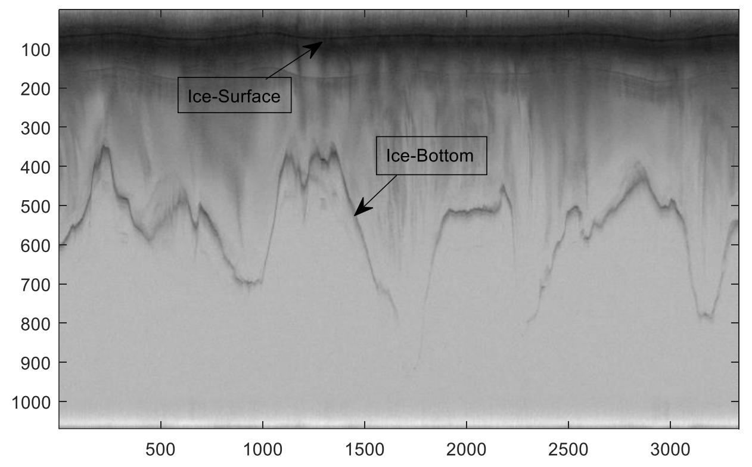

Fig.2 2D echogram of the ice sheet

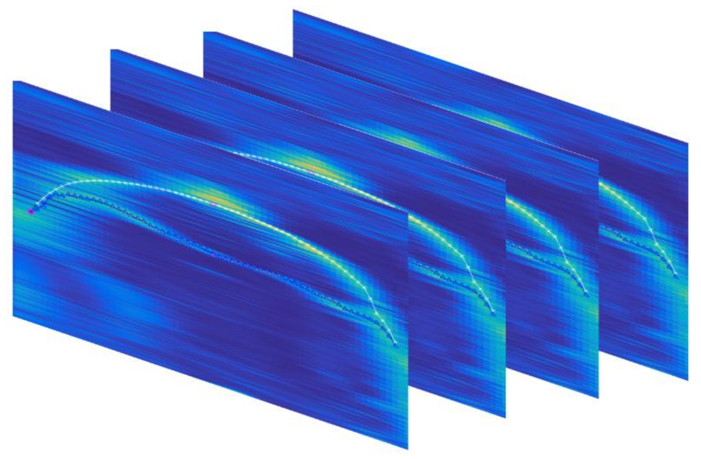

Fig.3 3D echogram of the ice sheet

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* Viterbi algorithm is a dynamic programming algorithm for finding the most likely sequence of hidden states – in our cases, finding the set of column-to-column transitions that produces the lowest cost of labeling the interfaces.

Why are the problems we face to analyze the ice topography imagery after the algorithm is applied?

Although computer algorithms do a good job at depicting where the interfaces are, several parameters of the algorithm can be "tuned" so that the algorithm may be able to return an even more accurate result. Concretely, what we want to do in this project is to explore the parameter space, to find better combinations of parameters that can further reduce the difference between the automated result and the ground truth (manually labeled data).

Optimization using Grid Search

The method we employed for optimization is Grid Search, a straight-forward method to test a set of models that differ from each other in their parameter values. While there are more advanced methods in this line of work, we use Grid Search because this approach enables us to easily utilize the parallel computational resources to test the models. As long as the parameter space tested is sampled finely enough, it is guaranteed to find the best answer within the parameter ranges specifies. Although it is not efficient, the computation time is not much more than some other advanced methods provided that the model uses only a few parameters [7].

With the tools developed by the CReSIS Signal Processing Lab, we are able to visualize the result of the Viterbi algorithm applied to each "slice" of the 3D image (Fig. 4). This helps us to select a good range for each parameter. For example, the smoothness coefficient is a parameter of the Viterbi algorithm that reduces the number of sharp edges in the lines that depict the interfaces. By inspecting a range of values, we have found a reasonable range for the smoothness coefficient.

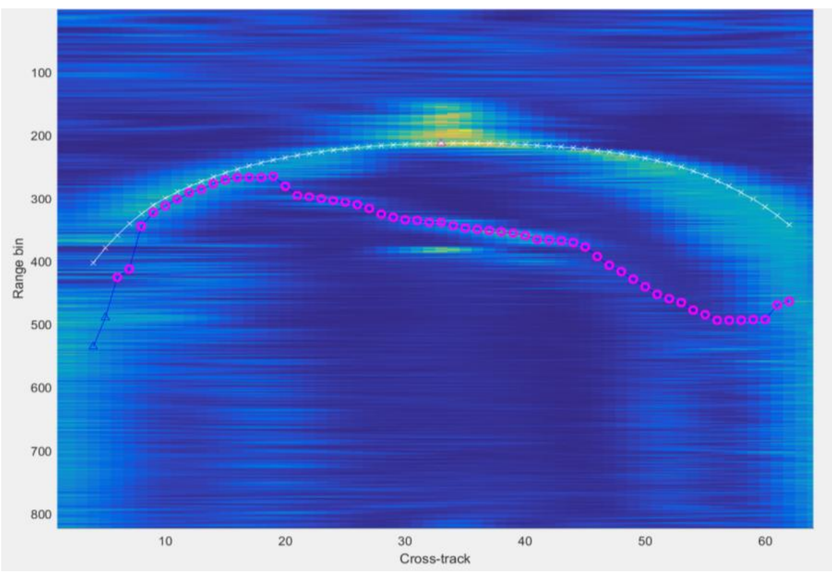

Fig.4 Applying the Viterbi algorithm to detect the bedrock location in the cross-section of a 3D image (pink dotted line).

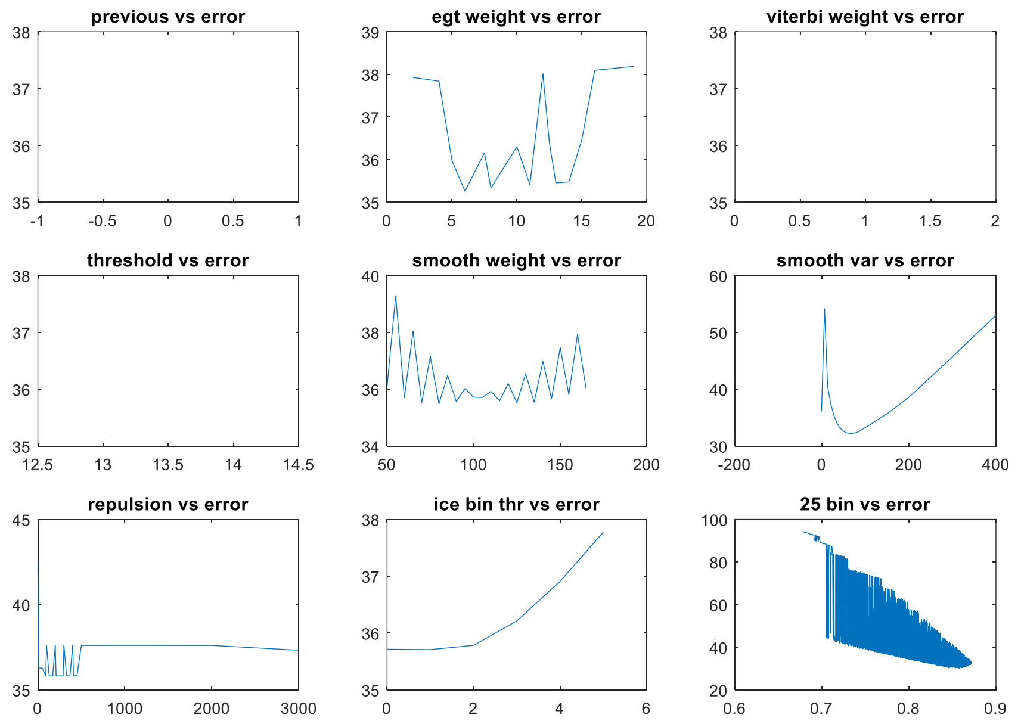

Fig. 5

Note that it is impossible to test out all the possible values for each parameter, since the number of possible combinations of parameters is quite large. Thus, our strategy is to use a coarse grid first, that is, we start by only testing a few values for each parameter. Then, by identifying and narrowing down the range of each parameter, we now have a refined version of the grid to conduct a finer grid search.

To see the relationship between each parameter to the error (Fig. 5), we take a look at the average error it produces.

Results

We have tested Viterbi algorithm with the parameters we've selected from the optimization on the entire dataset obtained from the 2014 Greenland P3 field campaign to detect the interface of the ice-bottom. The result shows that we have improved the mean error from 9.8 to 8.68, an 11.4% improvement from the previously (manually chosen) parameters.

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Acknowledgements

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