Geoscience Laser Altimeter System sparse ICESat data processing based on F-transform

Andriy Yerokhin
Computer Science Faculty
Kharkiv National University
of Radio Electronics
Kharkiv, Ukraine
andriy.yerokhin@nure.ua

Andrii Babii
Department of software engineering
Kharkiv National University
of Radio Electronics
Kharkiv, Ukraine
andrii.babii@nure.ua

Oleksii Turuta
Department of software engineering
Kharkiv National University
of Radio Electronics
Kharkiv, Ukraine
oleksii.turuta@nure.ua

Abstract — **In the paper, we present the 3D filtering method of surface approximation based on FT-smoothing proposed to estimate glacier thickness change. Our method based on ICESat/GLAS Altimetry Data and SRTM-DEM Data. Processed data of satellite measurements at the coordinate surface usually placed sparsely, collected in "Satellite track". For interpolation, we are using 2D membership function. This approach is kind of a generalization of the single-dimension method. The result provides estimated by RMSE, we have managed a number of fuzzy components for improving RMSE.**

Keywords — F-transform, SRTM dataset, GLAS, fuzzy transform methods.

I. INTRODUCTION

Actual environmental papers address global warming, the influence of the greenhouse effect on the average temperature of the Earth's climate system. One of the symptoms of the temperature changing is glacier thickness change. Natural disasters, floods, rising sea level are the result of the melting of mountain glaciers and polar ice caps, confirms the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) [1].

There are various ways to measure glacier thickness change, such as:
1) direct measurements;
2) difference of multi-temporal Digital Elevation Models (DEM) [2,3];
3) satellite radar altimetry [4].

Direct measurements of glacier thickness require significant resources. Differencing multi-temporal DEMs [2,3] permit remote measurements, however, the disadvantage of this approach is time-consuming methods of obtaining data, which affects the accuracy of measurements. In the paper, we use the altimetry data of satellite radar, measurements obtained in 2003–2009 by the Geoscience Laser Altimeter System (GLAS) [4-6]. On the other hand, the existing hardware limitations in data processing [7] lead to the need to improve approaches based on fuzzy transformations.

1.1.Datasets

In this section, we present two datasets for smoothing (denoising) on the ICESat/GLAS Altimetry Data and SRTM-DEM Data.

1.1.1. ICESat/GLAS Altimetry Data

ICESat (Ice, Cloud, and land Elevation Satellite) was launched 13 January 2003. From 2003 to 2009, the ICESat mission provided multi-year elevation data needed to determine ice sheet mass balance, cloud and aerosol heights. The sole instrument on satellite was the Geoscience Laser Altimeter System (GLAS), a space-based LIDAR. GLAS produces a series of approximately 60-70 m diameter laser spots that are separated photoprints by nearly 170 m along the spacecraft's ground track (see figure 1). We can obtain, that in different years repeated tracks do not match exactly, distance is from some hundred meters to some kilometers. GLAS data provides about 10cm of vertical accuracy and 5 cm of horizontal accuracy [8,9].

1.1.2. SRTM-DEM Data

The SRTM (Shuttle Radar Topography Mission) used technique interferometric synthetic aperture radar and preprocessed by Intermap Technology. The original SRTM data was preprocessed and filled the voids. In the paper, we

Fig. 1. Satellite track and relief

used the CGIAR-CSI versions [10], it provides the best global coverage full resolution SRTM dataset. This dataset has a resolution around 90 m corresponding to 3-arc seconds at the equator [11]. The fusion SRTM DEM and GLAS are providing by our method.

1.2. Methods

There are several main approaches to detect changes in glacier surfaces elevation using NASA's Ice, Cloud, and land Elevation Satellite (ICESat) laser altimetry data: crossovers, repeat tracks, overlapping footprints, triangulated irregular networks.

1.2.1. Crossovers.

This approach is common and widely used. To measure elevation using this method [12] one ascending track and one descending tracks required. Measurement in each tracks interpolated using linear function separately and return point of intersection of this two tracks with two interpolated values (or measured values in very rare cases, when point were measured by both descending and ascending track). It allows to compare this values and find difference of elevation and difference in time for two interpolated measurements of time. As result we receive measurement points at each intersection of ascending and descending tracks in the interest area [13]. Also in preprocessing crossovers created by two intersecting tracks which were measured close in time (from the same campaign) are removed. Usually it's important to define threshold for the total interpolation distance between crossovers and centroid of all crossovers. Further development of this method gives method called 'super crossover' which use clusters of crossovers and elevation change estimated between each cluster using linear regression.

1.2.2. Repeat tracks.

This method based on the usage of the repeatability of the satellite orbit of the ICESat in the 91-day period. It based on idea that distance between repeat tracks and reference track are relatively small and amount of collocated data can be collected for the campaign. And we can compare data between different campaigns. Problems here can be related with measurement fails (clouds, measurement errors, bad weather conditions) and we receive sparse date instead of set of collocated points. Models similar to [14] using predefined regions (size depends on sparsity of collected points) usually it's a non-overlapping cells in the grid with the centers on the reference track. Example of this approach is article [15] which using polynomial fitting of Sparse ICESAt to estimate elevation on each predefined area. There are at least four repeat tracks required within one predefined area to obtain information about temporal change in elevation or cross-track slope.

1.2.3. Overlapping Footprints.

These methods were used in papers [16,17] and it uses coincident locations of the laser altimetry areas. Data of measurements received by shots along the satellite track and packed into granules containing information by track and campaign. Laser footprints are not circular and shots are overlapping if the distance between their footprints less than maximum major axis. Depending on coordinates of area, count of intersections of the footprints may vary. There are at least three overlapping laser footprint areas required to estimate elevation change rate for selected cell. And depending on this cell size also will vary for different coordinates of interest area. Also sometimes non-overlapping but 'near neighbors' an be included into overlapping set because footprints are not round and change in orientation in one of the selected shots can be used to create an overlap.

1.2.4. Triangulated Irregular Networks.

Method described in [18]. Idea of the method in grouping of all footprints of the laser altimetry data into two-years blocks and fitting of the triangulated irregular network (TIN) to measurements within the block. Maximum distance threshold between points should be defined; it will depend on coordinates and density of laser measurements. Than, we can calculate linearity interpolated elevation for each TIN facet and estimate elevation changes for interest areas comparing overlapped TINs for different 2-years blocks. Caveats of this approach related with assumption that slope fitted by TIN facet icon curved and the rate change through time between the measurements forming TIN is constant. Just as with previous methods we can use larger.

II. ICESAT DATA PREPROCESSING

Data points received after pre-processing and registering of satellite measurements at the coordinate surface usually placed sparse. Points collected at different time usually placed at 'satellite tracks'. Elevation changes estimation methods based on cross-over comparison (see figure 2) can't be used for areas where satellite tracks did not intersected.

We propose to use method based on fitting of the surface model to receive and compare interpolated values for such cases. Each registered point will store information about x-coordinate, y-coordinate and elevation measured by satellite. Than we propose to apply interpolation method F-transform [19] to fit model on sparse points set.

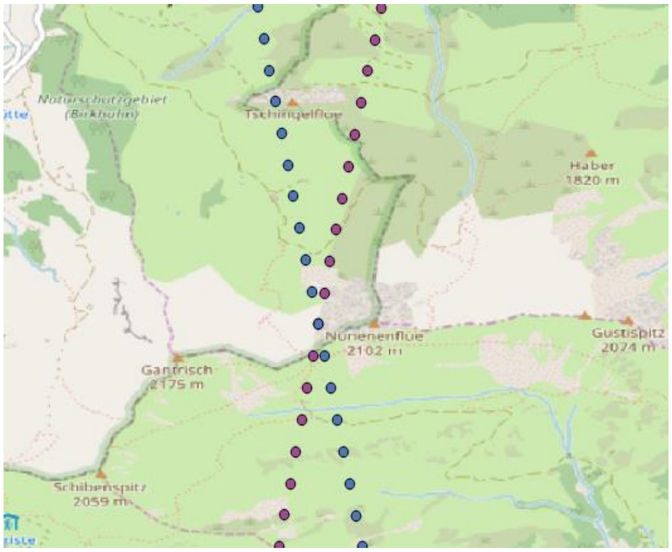

Fig. 2. Crossed sattelite track collected in different time

A. *Fuzzy partition*

We will define fuzzy partitions according to Ruspini condition [20]. Centers of the partitions placed can be placed uniformly or non-uniformly. In this work we will use uniform partition center placing fitted into regular grid on 2 dimensional *XY* coordinate plane. Each fuzzy partition will have 2 dimensions. Approach of partitioning is a generalization of single-dimension method.

For each coordinate axis X and Y, on intervals $[a_x,b_x],[a_y,b_y]$ let S be vector containing fixed nodes on interval so that $s_1=a$, $s_m=b$ and $m\geq 2$. The membership functions $A_1...A_m$ of the fuzzy sets should fulfill the following conditions [21] for $i=1,...,m$:

1. A_i is continuous;

2. A_i strictly increases on $[s_{i-1},s_i]$ and strictly decreases on $[s_i,s_{i+1}]$;

3. $A_i:[a,b]\rightarrow[0,1], A_i(s_i)=1$;

4. $A_i(s)=0\, if\; s\notin(s_{i-1},s_{i+1})$, where we set $s_0=a$ and $s_{m+1}=b$;

5. For all $s\in[a,b]$,

$$\sum_{i=1}^{m}A_i(s)=1 \qquad (2)$$

Different functions can be used as membership function A . Shape of the function and the set of centers should be chosen before the computation, after pre-processing step depending on topographical characteristics of the surface.

B. *FT-transform for interpolation.*

We propose approach similar to published in article [22]. Let the fitted surface has rectangle form at XY projection: $[M_a,M_b]\times[N_a,N_b]$, where M_a,M_b are boundaries of the surface on X-axis, and N_a,N_b - boundaries on Y-axis. Function f cover surface represented by measurement points (x,y,z), where z – elevation at coordinates (x,y).

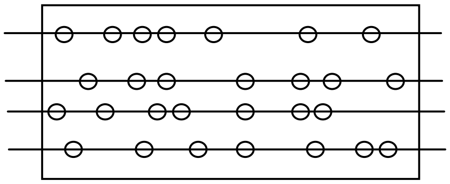

Fig. 3. Sketch map of ground tracks of GLAS. Different lines denote different tracks.

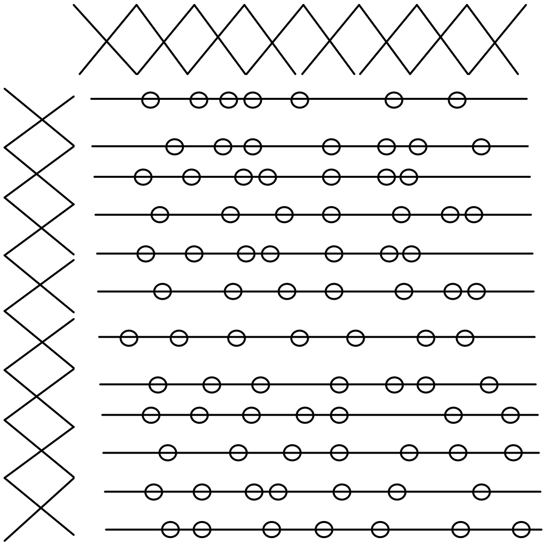

Fig. 4. Triangle membership functions and fuzzy partitions applied to ground tracks of sattelite measurements.

Let $A_1,...,A_m$ and $B_1,...,B_n$ be membership functions for partitions on X and Y axes. Each point in set covered by membership functions of 2D fuzzy partition with membership functions A_i and B_j if $A_i(x)>0$ and $B_j(y)>0$.

Let's define Z as elevation value at (p_l,q_k) , where p_l it is x-axis value, q_k - y-axis value. Let's define matrix of F-components as $m\times n$ matrix of real numbers $[F_{kl}]$

F-transform of f with respect to $\{A_1,...A_m\}$ and $\{B_1,...,B_n\}$ for all $i=1,...,m, j=1,...,n$ will be based on equations proposed in [20] and can be re-formulated as follows:

$$F_{ij}=\frac{\sum_{l=M_a}^{M_b}\sum_{k=N_a}^{N_b} f(p_l q_k)A_i(p_l)B_j(q_k)}{\sum_{l=M_a}^{M_b}\sum_{k=N_a}^{N_b} A_i(p_l)B_j(q_k)} \qquad (3)$$

The inverse transformation is applied to receive interpolated values for coordinates not existing in start measurements set:

$$\hat{f}(k,l)=\sum_{i=1}^{m}\sum_{j=1}^{n}F_{ij}A_i(p_l)B_j(q_k) \qquad (4)$$

Using function $\hat{f}$ we can interpolate elevation levels for coordinates not presented in 'satellite tracks' but placed inside area of interest and compare it with measurements taken at other time period.

III. IMPLEMENTATION AND RESULTS

The experiments were carried on Global Land Surface Altimetry Data (GLA14) GLAS dataset. We choose areas

TABLE I. EXPERIMENT SITES

Experiment site title	***Coordinates***
Yanong glacier	96.56° E, 29.38° N
Naimona'nyi glacier	81.32° E, 30.45° N
Guliya glacier	81.47° E, 35.24° N
Chasku Muba glacier	77.16° E, 35.90° N

described in article [14] to make experiments with IceSat data interpolation. This areas are: Yanong glacier, Naimona'nyi glacier, Guliya glacier, Chasku Muba glacier. Coordinates of these test areas are provided in Table I.

Results of interpolation listed in Table II, based on SRTM data for this test sites. The performance of the filter is measured using root mean square error (RMSE) calculated to compare fitted surface and real surface. For experiments we used different number of F-components defining centers of the fuzzy partition. In the tables listed best values for the fuzzy smoothing of defining area. Increasing number of fuzzy components (m , n) we decreasing RMSE, but we restricted by count of existing measurement points.

TABLE II. EXPERIMENT SITES

Experiment site title	**RMSE (m)**
Yanong glacier	23,3
Naimona'nyi glacier	11,2
Guliya glacier	9,4
Chasku Muba glacier	3,7

We observed that the proposed approach returns satisfactory results for fitting of complex glassier surface.

CONCLUSION AND FUTURE DEVELOPMENTS

In this paper method of surface approximation based on FT-smoothing proposed. Experiments were provided on areas with different level of roughness. Current study can be extended with information fusion with data received from satellite for GLAS changes in time.

In future developments non-uniform and generalized fuzzy partitions and its optimal parameter selection should be used instead of proposed implementation using uniform fuzzy partitions.

Membership function selection also can be defined as a perspective development.

REFERENCES

[1] IPCC. Workshop Report of the Intergovernmental Panel on Climate Change. In Proceedings of the Workshop on Sea Level Rise and Ice Sheet Instabilities, Stockholm, Sweden, 20–21 September 2013.

[2] Surazakov, A.B.; Aizen, V.B. Estimating Volume Change of Mountain Glaciers Using SRTM and Map-Based Topographic Data. IEEE Trans. Geosci. Remote Sens. 2006, 44, 2991–2996.

[3] Gardelle, J.; Berthier, E.; Arnaud, Y. Slight mass gain of Karakoram glaciers in the early twenty-first century. Nat. Geosci. 2012, 1–4.

[4] Moholdt, G.; Nuth, C.; Hagen, J.O.; Kohler, J. Recent elevation changes of Svalbard glaciers derived from ICESat laser altimetry. Remote Sens. Environ. 2010, 114, 2756–2767.

[5] Neckel, N.; Kropacek, J.; Bolch, T.; Hochschild, V. Glacier mass changes on the Tibetan Plateau 2003–2009 derived from ICESat laser altimetry measurements. Remote Sens. Lett. 2014, 9, 1–8.

[6] Slobbe, D.C.; Lindenbergh, R.C.; Ditmar, P. Estimation of volume change rates of Greenland's ice sheet from ICESat data using overlapping footprints. Remote Sens. Environ. 2008, 112, 4204–4213.

[7] O.M. Ulyanov, M.S. Plakhov, A.I. Shevtsova, O.O. Ulyanova, A.A. Skoryk, V.N. Tkachev. Testing the speed of the FFT using the NVIDIA graphic cards // YSF 2015 – International Young Scientists Forum on Applied Physics 29 Sept.- 2 Oct. 2015, Kharkiv, Ukraine. – 4 p.

[8] Phan, V.H. Observing Changes in Lake Level and Glacial Thickness on the Tibetan Plateau with the ICESat Laser Altimeter. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2015.

[9] Duong, H.; Lindenbergh, R.; Pfeifer, N.; Vosselman, G. Single and two epoch analysis of ICESat full waveform data over forest areas. Int. J. Remote Sens. 2008, 29, 1453–1473.

[10] Jarvis, A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org).

[11] Phan, V.H.; Lindenbergh, R.C.; Menenti, M. Orientation dependent glacial changes at the Tibetan Plateau derived from 2003–2009 ICESat laser altimetry. Cryosphere Discuss. 2014, 8, 2425–2463.

[12] 3.2. ZWALLY, H. J., et al. ICESat's laser measurements of polar ice, atmosphere, ocean, and land. Journal of Geodynamics, 2002, 34.3-4: 405-445.

[13] B. E. Smith, C. R. Bentley, and C. F. Raymond, "Recent elevation changes on the ice streams and ridges of the Ross Embayment from ICESat crossovers," Geophys. Res. Lett., vol. 32, no. 21, p. L21S09, Oct. 2005.

[14] I. M. Howat, I. Joughin, M. Fahnestock, B. E. Smith, and T. A. Scambos, "Synchronous retreat and acceleration of southeast Greenland outlet glaciers 2000–06: Ice dynamics and coupling to climate," J. Glaciol., vol. 54, no. 187, pp. 646–660, Dec. 2008.

[15] HUANG, Tianjin, et al. A New Method to Estimate Changes in Glacier Surface Elevation Based on Polynomial Fitting of Sparse ICESat—GLAS Footprints. Sensors, 2017, 17.8: 1803.

[16] D. C. Slobbe, R. C. Lindenbergh, and P. Ditmar, "Estimation of volume change rates of Greenland's ice sheet from ICESat data using overlapping footprints," Remote Sens. Environ., vol. 112, no. 12, pp. 4204–4213, Dec. 2008

[17] B. C. Gunter et al., "Empirical estimation of present-day Antarctic glacial isostatic adjustment and ice mass change," Cryosphere, vol. 8, pp. 743–760, Apr. 2014

[18] H. D. Pritchard, R. J. Arthern, D. G. Vaughan, and L. A. Edwards, "Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets," Nature, vol. 461, pp. 971–975, Sep. 2009

[19] P. Vlašánek and I. Perfilieva, "Image reconstruction with usage of the F-Transform," in International Joint Conference CISIS'12-ICEUTE' 12-SOCO' 12 Special Sessions, 2013, pp. 507–514.

[20] E. H. Ruspini, "A new approach to clustering," Information and control, vol. 15, no. 1, pp. 22–32, 1969.

[21] I. Perfilieva, "Fuzzy transforms: Theory and applications," Fuzzy sets and systems, vol. 157, no. 8, pp. 993–1023, 2006.

[22] A. Yerokhin, V. Semenets, A. Nechyporenko, A. Babii, O. Turuta. F-transform 3D Point Cloud Filtering Algorithm // Proc. of the 2nd IEEE International Conference on Data Stream Mining & Processing. 21-25 August 2018, Lviv, Ukraine. - P.524-527.