Temporal Multi-Looking of SAR Image Series for *Glacier Velocity* Determination and Speckle Reduction

(click title for abstract)

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*Sneak preview:*

*But don’t forget to check out the slides to learn the method behind “motion compensation”.*

https://n.ethz.ch/~sleinss/downloads/Aletsch_Motion_Compensation.mp4
Motivation

Problem: Glacier velocity estimation from synthetic aperture radar (SAR) images requires relatively large image template for offset tracking due to radar speckle which appear as uncorrelated noise.

Question: Can we combine time series of SAR images to create high-resolution, speckle-reduced radar images with enhanced visibility of surfaces features, and to estimate simultaneously the glacier surfaces velocity field?

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Single radar image (TanDEM-X):
-- strong radar speckle (noise).

Single image, 5x5 lowpass speckle filter:
+ speckle reduced,
-- details lost.

Average of 12 image:
+ stable features well visible
-- glacier surface shows motion blur.

Spatial average
-- details lost by averaging

Temporal average
+ details visible for stable terrain
-- Motion blur (details lost "in time")

We want this level of details - also for moving glaciers!
Idea: motion-compensated time-averaging

The camera follows the motion of the car:

+ the car is focused
– the background is blurred.

⇒ Shift SAR images locally to follow the motion of the glacier.

We want the entire image focused!

⇒ Apply auto-tracking for every pixel (define a velocity-sensitive autofocus method).

Our method is motivated by video processing for image stabilization.
**Method: motion-compensated time-averaging to determine surface velocity**

Split stack of N SAR images into two sub-stacks.

- Choose a 2D velocity $v_{test}$
- Shift images $i$ locally by the offset $\Delta x_i = (t^* - t_i) v_{test}$
- Average shifted (interpolated) images in sub-stacks
- Features which move with $v = v_{test}$ appear focused and will match.

Warp images and average sub-stack.

Calculate local Normalized Cross Correlation: NCC ($v_{test}$) between templates of sub-stacks. (Similar to autofocus of digital cameras).

For every pixel, find $v_{test}$ which maximizes NCC (i.e. where the templates match best).

**Method summary:**
- Basically, we sample the NCC in the spatial domain. Therefore, a computationally efficient optimization is required (pyramids).
- For offset estimation we assume a locally constant velocity.
- Instead of correlation of image pairs, we first average N/2 images for speckle reduction and correlate then the averaged sub-stacks.
- Because we reduce speckle we can use smaller correlation windows (30x30 px, instead of e.g. 96 x 96 px).
Results I/IV

We correlate “speckle-reduced” radar images (sub-stacks) → surface feature better visible
→ Improved cross correlation → smaller template size required for image matching
→ Result: High resolution velocity maps + high coverage also in difficult areas.
Results II/IV

Velocity magnitude

**Test site:**
Aletsch Glacier, Switzerland

**Radar images:**
TanDEM-X
Winter 2011/2012 (11 days repeat cycle).

**Our method** (left) provides robust velocity estimates (even in the accumulation zone) with high area coverage and high spatial resolution.

With **pair-wise cross-correlation** (right) many areas cannot be tracked, even at lower resolution.

**Our method:**
N = 10 images (1 winter), Patch size: 30 x 30 px.

**Pair-wise cross correlation,**
Patch size: 100 x 100 px.
Results III/IV

Velocity orientation

The orientation of the velocity vectors is a good indicator how well the glacier surfaces can be tracked.

**Our method:**
N = 10 images (1 winter),
Patch size: 30 x 30 px.

**Pair-wise cross correlation:**
Patch size: 100 x 100 px.
Results IV/IV: Validation of velocity field with GPS

22 Points measured with GPS

GPS campaign in April 2019
Animation of glacier flow field

The time $t^*$ for which a sub-stack is averaged can be arbitrarily chosen. Therefore smooth movies can be created from time series containing gaps based on the obtained velocity field.

Click here to watch the standard (stop-motion) animation of input image time series: https://n.ethz.ch/~sleinss/downloads/input-aletschglacier-tandemx-2011-2018-timelapse-h264.mp4

Click here to watch the smooth, speckle-free animation - based on computed velocity fields and stack averaging: https://n.ethz.ch/~sleinss/downloads/flowcompensated-aletschglacier-tandemx-2011-2018-timelapse-h264.mp4

Summary and Conclusion

• For pair-wise cross correlation with SAR images relatively large image templates (~100x100 pixels) are required due to radar speckle. This limits the spatial resolution of obtained velocity fields. Cross-correlation often fails when no clearly trackable features are visible in the speckle-affected radar images.

• In our method we estimate the mean velocity from a (not necessarily equidistant) time series of about N = 8...16 images.

• The time series is split into two sub-stacks of N/2 images. Then every pixel in each SAR image is shifted according to an estimated time-dependent offset with respect to an arbitrarily chosen reference date (preferably the average time of all images). Then the two substacks are averaged along the time axis. Speckle are highly reduced.

• If the estimated offset agrees with the true offset (i.e. the true velocity was found), image features don’t show motion blur and the cross-correlation of the two averaged sub-stacks is maximized.

• Time-averaging reduces the temporal resolution of velocity fields but enhances the spatial resolution (we use a template size of only 30 x 30 pixels for SAR images).

• Compared to pair-wise cross correlation our method is more robust to (speckle-) noise. Therefore, velocity fields can be estimated even in terrain which shows very weakly trackable features (e.g. the accumulation zone of glaciers). However, we assume a constant surface velocity during the stack acquisition period.

• The reference date, to which the sub-stacks are averaged, can be arbitrarily chosen. Therefore, smooth, speckle-reduced surface flow animation of the glacier surface can be generated based on a limited (and even unevenly spaced) number of SAR images.

• The presented method is motivated from video processing for image stabilization. It could improve future tracking methods and is well suited to exploit the large number of emerging free and globally available high resolution SAR image time series.