REGULARIZATION OF DISPLACEMENT FIELDS FOR GLACIER MONITORING

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1. INTRODUCTION

Synthetic aperture radar (SAR) images provide scattering information which can be used under any weather conditions for glacier monitoring. The purpose is to estimate a displacement field characterizing at each position the local speeds and orientations of the glacier movement. The recent method proposed in [1] builds a vector field from the similarities existing between two SAR images co-registered on static areas and sensed at different time. The local movement is evaluated by researching in one acquisition the patterns which are similar to those present in the other acquisition. This abstract proposes to use the correspondences between patterns inside a two step estimator of the vector field. The first step is the local estimation of the displacement vectors using the maximum likelihood estimator. The presented results show that this local estimator seems to be efficient in textured area. However, the spatial coherence of the vector field is not insured in homogeneous area. Then, a second step of regularization seems to be necessary to deal with such unreliable estimated vectors. Different regularization methods, which could be used in the final paper, are proposed to improve the spatial coherence of the displacement field.

2. DISPLACEMENT ANALYSIS WITH UNCORRELATED SPECKLE NOISE

Let A and A' be two amplitude images co-registered on static areas and sensed at different time. We denote by A_s and A'_t the amplitudes measured respectively at position s in A and at position t in A'. The idea is to estimate at each position s of the glacier a displacement vector $\overrightarrow{v_s}$ reflecting the speed and the orientation of the local movement. The amplitude A_s and A'_t are assumed to follow a multiplicative speckle noise model such that:

$$A_s = \sqrt{R_s} \times \eta_s \qquad (1)$$

$$A'_t = \sqrt{R'_t} \times \eta'_t \qquad (2)$$

where R_s and R'_t are the underlying reflectivities at site s and t, and η_s and η_t are two realizations of two random variables following a normalized Rayleigh distribution. The speckle is assumed to be spatially decorrelated inside each image and temporally decorrelated between both images. This last assumption holds according to the unstable scattering nature of the glacier surface. The realizations η_s and η_t are then decorrelated and to analyze the displacement vector $\overrightarrow{v_s}$ from the amplitude images A and A' is then equivalent to analyze it directly from the reflectivity images R and R'.

3. LOCAL ESTIMATION OF THE MOVEMENT

In order to estimate the displacement vector $\overrightarrow{v_s}$, the neighborhood of s in the reflectivity image R and the neighborhood of $t = s + \overrightarrow{v_s}$ in R' are assumed to be similar when the position s corresponds on the position t. Indeed, corresponding objects are assumed to be seen in both images in similar patterns. That is the idea of texture tracking algorithms as proposed in [1]. This assumption can be translated by the similarity of each values belonging to rectangular patches centered around s and t, i.e $R_{s,k} = R_{t,k}$ where $_{s,k}$ and $_{t,k}$ denotes the k-th pixels in the respective patches. In practice, the information $R_{s,k} = R_{t,k}$ is latent since the underlying reflectivity images R and R' are

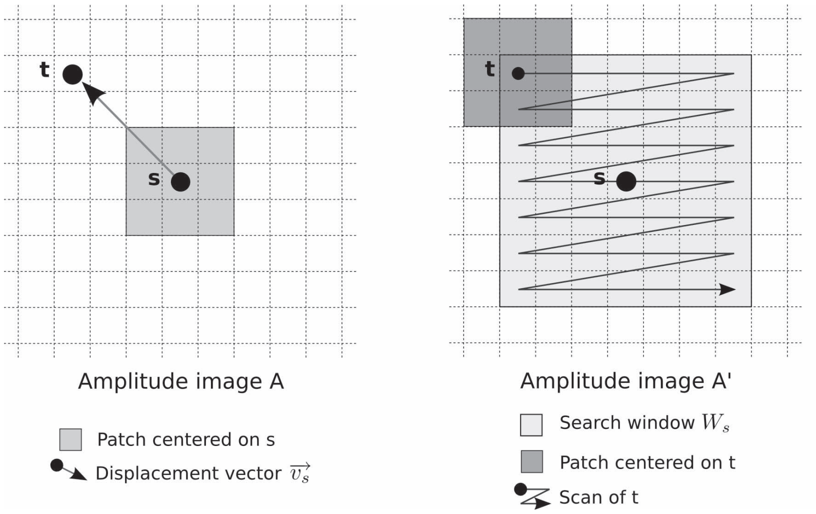

Fig. 1. Illustration of the proposed tracking method

unknown. Then, we suggest to estimate the patch similarities by using the likelihoods of $R_{s,k} = R_{t,k}$ for all k with respect to the observations $A_{s,k}$ and $A'_{t,k}$. This leads to the following definition based on similarity likelihoods:

$$p(A, A'|\overrightarrow{v_s}) \triangleq \exp\left[-\sum_k \log\left(\frac{A_{s,k}}{A_{t,k}} + \frac{A_{t,k}}{A_{s,k}}\right)\right]. \tag{3}$$

This criterion has been introduced in [2] where its efficiency has been demonstrated for SAR image denoising. Since it is based on the speckle noise distribution, and as shown in (3), this criterion has the ability to deal well with the multiplicative nature of the speckle noise. Similar criteria based on different assumptions have also been proposed in [1]. These similarities are then used to provide a local estimate of the the displacement vector $\overrightarrow{v_s}$ in the maximum likelihood estimator [1]:

$$\hat{\overrightarrow{v_s}} = \arg \max_{\overrightarrow{v_s}|t \in W_s} p(A, A'|\overrightarrow{v_s}) \tag{4}$$

where W_s is a rectangular window centered around s. Figure 1 illustrates the procedure. For each candidate vector $\overrightarrow{v_s}$ inside the window W_s, the similarity between the patch centered on s and the patch centered on t is evaluated. The similarities are then used in the maximum likelihood estimator to provide a local estimate of the displacement vector $\hat{\overrightarrow{v_s}}$.

4. LIMITS OF LOCAL ESTIMATORS

The proposed local estimator presented in section 3 has been applied on two SAR images of the lower part of the glacier of Argentière (Alpes, France) sensed by TerraSAR-X on September 29th, 2008 and October 21th, 2008 respectively. The two SAR images have been previously co-registered on static areas. They have a resolution cell of 1.36×2.04 meters. Search windows of size 11×11 have been used (this corresponds on a maximum displacement of about 56 cm/day) and patches of size 101×101 have been chosen. A binary mask has been provided to localize the glacier surface. Figure 2 shows the estimated displacement field obtained from the two amplitude images of the glacier surface. At each position is represented the magnitude and the orientation angle of the local movement. The displacement is well recovered in regions where there is texture information such as the cracked parts formed by intersecting crevasses. The global movement direction follows the movement of the glacier and the estimated speeds reflects the ground truth with an average over the surface of 12.27 cm/day and a maximum of 41.12 cm/day in the breaking slope of “Lognan serac falls”.

Unfortunately the vector field seems to be irregular. First, geometric artifacts appears resulting to the use of square patches. Then, quantization effects are produced due to the selection of one vector among a finite set of

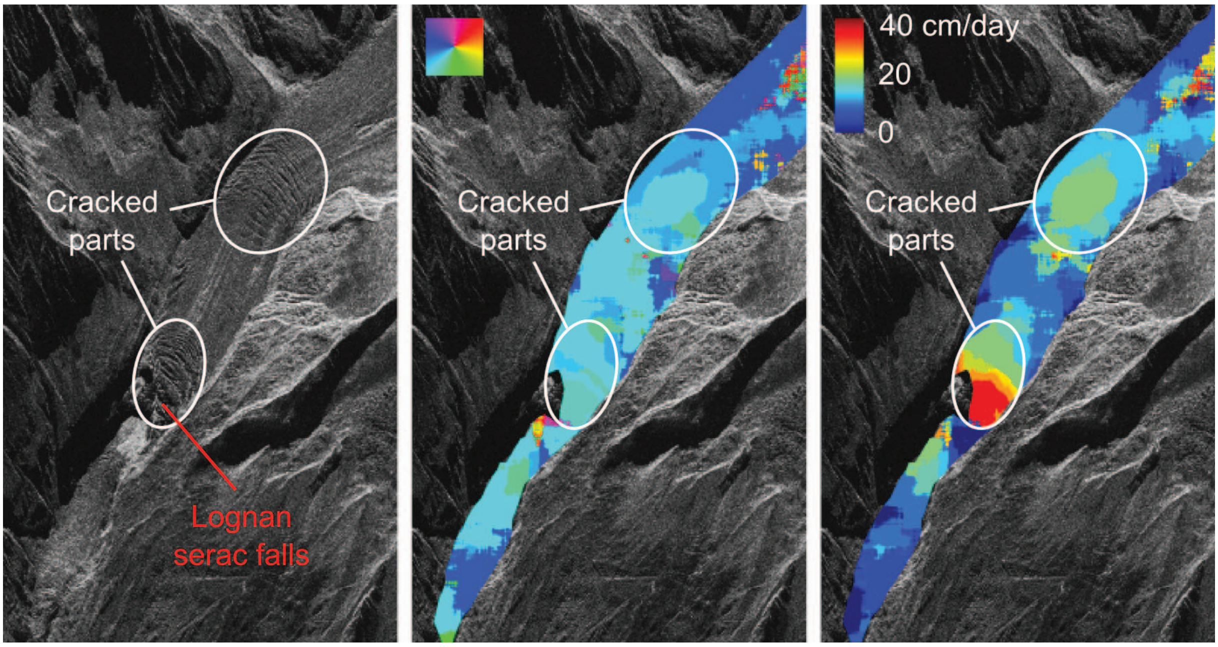

Fig. 2. (left) SAR image of the glacier of Argentière, (center) orientations and (right) speeds of the movement given by the maximum likelihood estimator. The cracked parts have been highlighted to show the efficiency of this local estimator in textured area and its limits elsewhere. The estimated speeds have an average over the surface of 12.27 cm/day and a maximum of 41.12 cm/day in the breaking slope of "Lognan serac falls".

vectors (the ones included in the search window). Finally, the obtained directions are not consistent in some homogeneous areas, where two neighbor vectors could have different norms and/or orientations. Indeed, the maximum likelihood estimator tends to select an arbitrary vector since the lack of textural information produces almost equiprobable vectors. Local estimators are then limited to provide a reliable displacement measure in such areas. We suggest in the next section to solve these issues with regularization methods considering the spatial coherence.

5. REGULARIZATION OF THE VECTOR FIELD

A regularization step will be used to improve the spatial coherence of displacement fields obtained by the local estimator presented in section 3. While correcting unreliable vectors in homogeneous area, regularization methods might also avoid geometric artifacts and quantization effects by producing a smooth vector field with a subpixelic precision. From the similarity likelihoods obtained inside each search window, confidence values can be attributed to all estimated vectors. These confidence values can be used to diffuse the information provided by reliable displacement vectors (high confidence) to unreliable vectors (low confidence). Two different strategies could be investigated to regularize the vector field:

- Gradient vector flow is an image processing method proposed in [3] for active contours. This method diffuses the information of given vectors in the whole image to produce a smoothed vector field. The obtained vector field preserves the original given vectors and force the field to be slowly-varying where there is no data. The problem is defined as the minimization of an energy which can be optimized by solving Euler equations with an iterative algorithm. This energy can be extended easily to our case and take account of vector confidences.

- Markovian random fields search a trade-off between data fidelity and regularization by using energy minimization. Data fidelity forces the regularized vector field to be as close as possible to the given vectors. The regularization term forces neighbor vectors to have similar orientations and norms. The confidence attributed to each vectors can be used to weight the data fidelity in order to regularize only the unreliable area while preserving reliable vectors. The iterated conditional modes algorithm [4] could be investigated to optimize this Markovian energy.

6. CONCLUSION

A new estimator for glacier monitoring is proposed. This one estimates displacement vectors by the use of similarities between patches extracted from two SAR images co-registered on static areas and sensed at different time. Patch similarity is expressed as the likelihood that two patches have the same underlying reflectivity given the observed noisy amplitude patches. This similarity proposed originally in [2] deals well with multiplicative speckle noise. These similarities are then used in the maximum likelihood estimator which is efficient in several situations. However, due to its local definition, irregular vector fields can be obtained. We suggest to use a regularization procedure on the estimated displacement field to refine the estimation in unreliable areas. Two main methods could be studied in the proposed paper. The first one is based on the gradient vector flow approach and the second one is based on Markov random fields. First results have been presented on this abstract. The vector field obtained by the use of the maximum likelihood estimator seems promising to guide well a regularization method.

7. REFERENCES

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