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Tensor Based Mean-Shift PolSAR Image Enhancement

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TENSOR BASED MEAN-SHIFT POLSAR IMAGE ENHANCEMENT

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ABSTRACT

The mean-shift approach uses a local estimation of the pdf and moves every data points toward the modes. The direction is calculated from the mean value of surrounding points weighted by a Gaussian kernel. An advantage of the technique is that both radiometric and spatial information could be used in the weighted mean calculation. For polarimetric SAR images, we use likelihood ratio as radiometric similarity or distance measure. The spatial distance between pixels is also used with a Gaussian weight. Contours are well preserved because pixels on one side are dissimilar to pixels on the other side. To improve contour preservation, we examine how the tensor of pixel position can be integrated into the weight calculation. The tensor is calculated from weighted pixel position inside a window. Good PolSAR image smoothing is obtained.

Index Terms— PolSAR image, mean-shift, image filtering, orientation tensor

1. INTRODUCTION

Modes of probability density function (pdf) could be used to define classes or clusters. The mean-shift approach uses a local estimation of the pdf and moves every data points toward the modes [1]. At a data point, we can estimate the local pdf by using a Gaussian kernel. The data point x is moved in the direction of higher density or in the direction of gradient ascent. For a point x , the mean m of surrounding points weighted by a Gaussian kernel is calculated. The direction is given by the difference between x and m , $-(m-x)$.

In previous works, the mean-shift filtering of one-channel SAR images uses the difference between two pixels as the radiometric distance measure [3] [4]. For multi-look PolSAR images, the pixel covariance or

coherency matrix Z_i could be viewed as a tensor value. In [5], a distance measure in tensor space is derived. This measure is complex and computing time consuming. A faster approximation is proposed. This approach exploits the characteristics of covariance matrix without relation to a probability model.

An advantage of the mean-shift technique is that both radiometric and spatial information could be used in the weighted mean calculation. The spatial distance between pixels is used with a Gaussian weighting function. Instead of this gradual weight, usual SAR image filtering techniques use a 0 or 1 weight [2]. The window is split into subparts and only one of those will be used for the mean calculation. We can also use a thresholding process to select the pixels that are used in the mean calculation.

In the mean-shift approach, all the useful information is integrated into the weights. At each iteration, the image smoothing is improved. Contours are well preserved because pixels on one side are dissimilar to pixels on the other side. To improve contour preservation, we examine how other contextual information can be integrated into the weight calculation.

2. MEAN-SHIFT FILTERING

In a homogeneous area, multi-look PolSAR pixel values Z_i could be viewed as draw from a Wishart distributed population. The likelihood ratio statistic is generally used to evaluate if two pixel values belong to the same population. It could also be used to evaluate the similarity between two pixels and to define a pixel distance, $D_r(Z_i, Z_j)$. For the Wishart distribution, the measure uses the log of the covariance matrix determinants,

$$D_r(Z_i, Z_j)^2 = 2 \ln |(Z_i + Z_j) / 2| - \ln |Z_i| - \ln |Z_j|.$$

This distance has been used in [6] for the mean-shift filtering of segment values. It is now applied on pixel

values.

This measure defines a mean-shift filtering process that gives good results. When we calculate the mean for pixel i , the weight of pixel j is

$$W_{i,j} = \text{EXP}\left\{-D_r(Z_i, Z_j)^2 / H_r^2\right\}$$

where H_r is the radiometric scaling factor. The mean is

$$M_{r,i} = \sum Z_j W_{i,j} / \sum W_{i,j}$$

where the summation is over a window centered on pixel i . At each iteration, the new pixel value is

$$Z_i^{\text{new}} = \alpha Z_i + (1 - \alpha) M_{r,i}$$

where α defines the convergence rate.

Usually, the distance between pixel i and pixel j is also considered in the weight calculation. Let p_i be the pixel position, $p_i = (x_i, y_i)^t$. For a circular Gaussian weighting function, we have

$$W_{i,j} = \text{EXP}\left\{-D_r(Z_i, Z_j)^2 / H_r^2 - D_s(p_i, p_j)^2 / H_s^2\right\}$$

where D_s is the Euclidian distance and H_s is the spatial scaling factor. H_s corresponds to the standard deviation σ of the Gaussian function.

3. POSITION TENSOR

The mean-shift filtering uses the radiometric information, D_r , to define the weight. Standard image filtering uses only the pixel position, D_s , to define the weight. In the previous equation, if we use only D_s , we have a circular Gaussian kernel filter.

Anisotropic diffusion is proposed to adapt smoothing to image gradient. The process is defined by a differential diffusion equation. It has been simplified and adapted to the filtering of PolSAR images [7]. The image gradient is used to define an adaptive directional kernel. A spatial 2x2 covariance matrix or tensor, $\Sigma_{s,i}$, defines the kernel orientation for pixel i . Higher weights are given to neighbour pixels in the main axis direction. This is obtained by using the Mahalanobis distance,

$$D_{s,\Sigma}(p_i, p_j)^2 = (p_j - p_i)^t \Sigma_{s,i}^{-1} (p_j - p_i).$$

Only $D_{s,\Sigma}$ is used in the weight calculation. The tensor $\Sigma_{s,i}$ contains a part of the radiometric information and is calculated from the image gradient.

The mean-shift filtering uses D_r and D_s . The spatial and radiometric dimensions are used to calculate the weights and both informations can be

updated. As the radiometric value, the pixel position can be moved toward its mean,

$$M_{s,i} = \sum p_j W_{i,j} / \sum W_{i,j}$$

Iteratively moving the pixel positions will change the pixel distances and the weight values. The updating of the pixel radiometric values Z_i will be affected.

The mean-shift approach allows the integration of others features. We are particularly interested in using the weights to define new attributes. We propose to use the weight to define the spatial tensor values $\Sigma_{s,i}$. For example, for a pixel on a road, its neighbours that are similar and have a large weight value will be located along the road. If the weights are considered, the neighbour dispersion will follow the orientation of the road. A tensor matrix should be used to integrate the orientation information of many pixels. The tensor is calculated from the weighted relative positions of surrounding pixels,

$$\Sigma_{s,i} = \sum W_{i,j} (p_j - p_i)(p_j - p_i)^t / \sum W_{i,j}$$

The tensor and the Mahalanobis distance $D_{s,\Sigma}$ can now be used instead of D_s . This new way to calculate the tensor avoids the difficult gradient calculation of noisy PolSAR images.

Furthermore, the spatial tensor can be added as new feature dimensions to the pixel values and the distance between tensors can be included into weight calculation. The S1 similarity measure of [8] is used to evaluate the distances between tensor matrices, $D_{\Sigma}(\Sigma_{s,i}, \Sigma_{s,j})$. Let v_i be the first (main) eigenvector of $\Sigma_{s,i}$ and v'_i be the second (perpendicular) eigenvector. Then, we have

$$D_{\Sigma}(\Sigma_{s,i}, \Sigma_{s,j}) = (P_{v_i}^i - P_{v_i}^j)^2 + (P_{v_j}^i - P_{v_j}^j)^2 \\ + (P_{v'_i}^i - P_{v'_i}^j)^2 + (P_{v'_j}^i - P_{v'_j}^j)^2$$

where P_V^i is the variance of $\Sigma_{s,i}$ along the vector $V \in \{v_i, v_j, v'_i, v'_j\}$. As the other data dimensions, the spatial tensor is also moved toward its mean.

The proposed mean-shift process uses the D_r , $D_{s,\Sigma}$ and D_{Σ} distances for the weight calculation. It takes into account the pixel positions, the radiometric values and the spatial tensors. Those values are update iteratively. There are complex interactions between the iterative updates of those values and the weight factors.

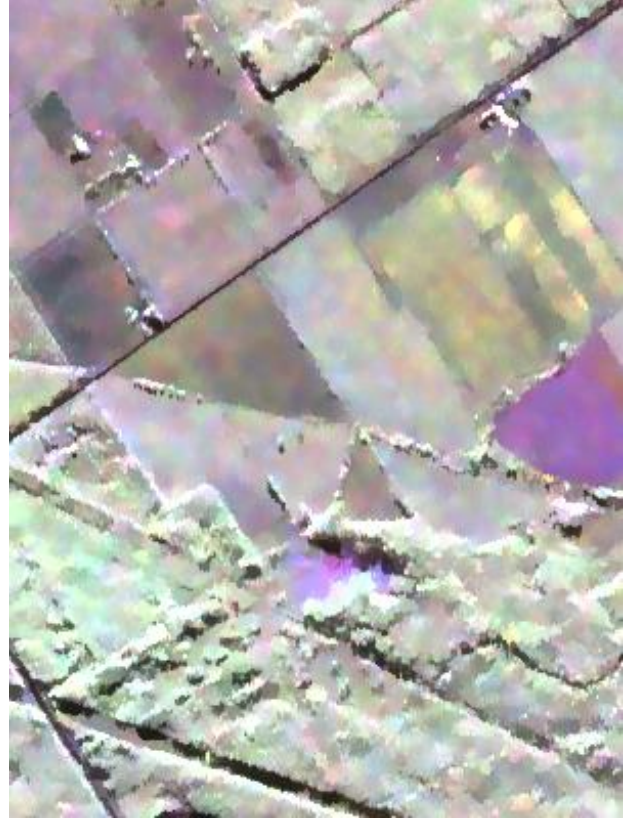
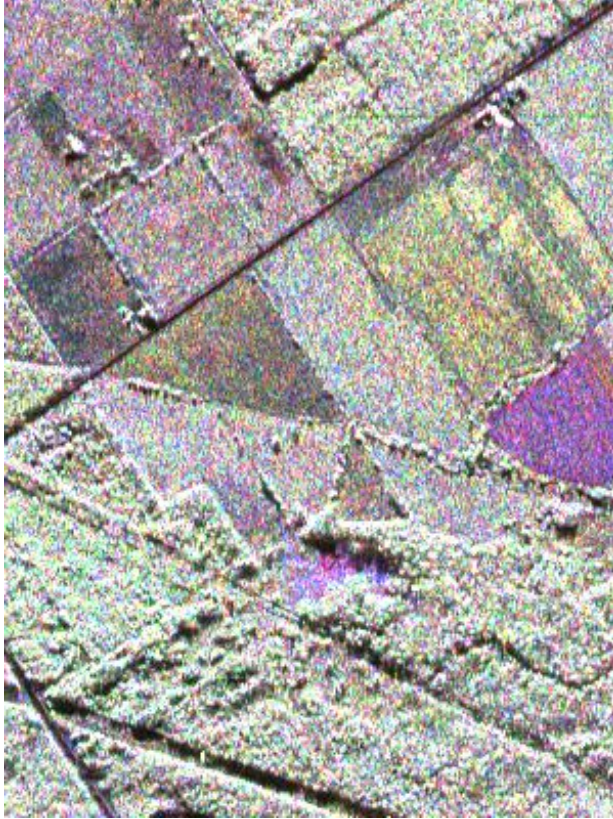


Fig. 1: Mean-shift filtering of a PolSAR image of Mer Bleu area (300x450 pixels, 9 looks), near Ottawa (left: original, right: result).

4. RESULTS

Fig.1 shows the mean-shift filtering result for a polarimetric SAR image of Mer Bleu area, near Ottawa. Five iterations of the mean-shift were used with an 11x11 filtering window. We have important noise reduction and smoothing inside fields, while edges and small targets are well preserved. For forest areas, we have important smoothing with preservation of structural elements. We have more important smoothing than the Lee Sigma filter [2] inside fields and better edge definition (lower edge blurring). We get finer grain and better detail resolution.

The results for the Oberfaffenhofen image are presented in Fig. 2. The image comes from the PolSARPro web site. There is important noise reduction in crop fields while thin structures are well preserved. They become even more visible. Building roofs are smooth with sharp and regular edges. Strong point targets are finely delimited. These figures show the good performances of the proposed mean-shift filtering process.

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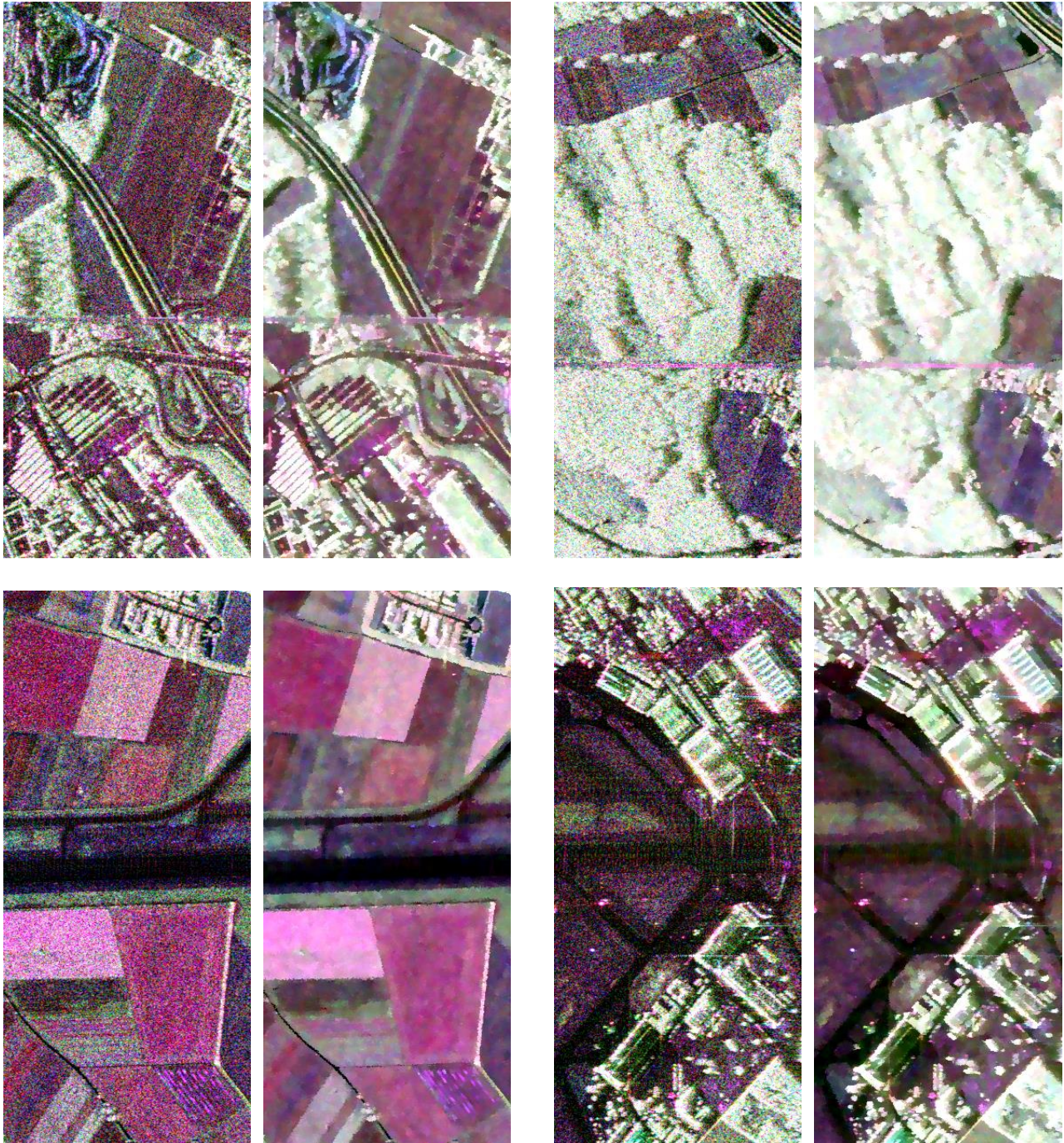


Fig. 2: Mean-shift filtering of Oberfaffenhofen PolSAR image, 4 subareas of 280x630 pixels (left: original, right: result).