# Application of Computer Vision Techniques in Modern SAR Systems

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***Abstract*— Synthetic aperture radar is a popular instrument for high-resolution imaging. Usage of state-of-the-art image and signal processing solutions allows to significantly increase the efficiency of such systems. In the paper two important applications of computer vision algorithms are described. In particular, usage of local feature extraction algorithms for the radar image stitching. This results in the automatical panorama creation without usage of the navigation data. In addition, the road location approach based on the stroke width transform and contour analysis is proposed. Application of the developed methods is illustrated with real SAR data examples.**

***Keywords—synthetic aperture radar (SAR); computer vision, image stitching, road detection; local features.***

## I. Introduction

Remote sensing instruments are widely used in various civil and military applications. Synthetic aperture radar (SAR) has become a very popular tool due to capability of achieving of the high-resolution level using physically small antenna [1]-[2].

It is evident, that efficiency of modern imaging systems is closely related with incorporated hardware and software solutions. The fast development of signal processing units and computational platforms allows to integrate sophisticated signal and image processing methods into the existing systems and even to obtain a lot of results in real-time. In particular, the techniques related with computer vision have a very high potential due to a theoretical possibility to make the radar systems almost fully automatic [3].

Unlike to optical systems, SAR systems are able to perform image formation in all weather and all lighting conditions. However due to the coherent nature, the obtained imagery has different properties than in the optical band [1], [4]. From one side, it gives additional benefits, since the real world objects demonstrate different scattering properties in different frequency bands and such multi-frequency fusion can give much more information for the further analysis. From another side, existence of speckle noise in SAR images complicates the analysis of such images and most of computer vision techniques can not be directly applied for the radar imagery.

In the paper, we demonstrate two important applications of computer vision algorithms for SAR data processing. In particular, it is illustrated that the radar image frames can be successfully superimposed by means on local feature extraction and matching algorithms instead of usage correlation based techniques and parameters measured by the navigation system. Also we describe the methodology for the automatical road location, which is accomplished based on the stroke width transform (SWT) together with the contour and histogram analysis. It is described how the proposed techniques can be applied in real problems arising in the research direction related with SAR imaging.

In Section II the idea of usage of speeded up robust features (SURF) algorithm for the SAR frame stitching is described. In Section III the approach for the automatical road location is described. It is shown how the extracted road information can be used in other SAR applications.

## II. SAR Image Formation and Stitching

SAR image formation is accomplished as a two-dimensional focusing of backscattered signals [1]. This can be achieved by a construction of matched filters. In the range-direction the reference functions of such filters are built based on a knowledge about the radiated signal while in the azimuth direction appropriate signal processing techniques are applied for synthetic aperture formation[1], [4]-[5].

Assuming that the SAR platform deviations are properly compensated by means of the conventional motion compensation procedures [1]-[2, [5]-[6], a SAR focusing algorithm can be applied to the SAR raw data. The review of the most popular SAR image formation methods can be found in [1].

Since the acquisition times can be significant, the collected SAR data should be processed in frame basis [7]. Fig. 1 illustrates this principle. Basically, each frame is processed with its own reference straight flight trajectory, the reference aircraft flight altitude, velocity, and orientation. We use the half-overlapping scheme in order to ensure the efficient stitching of the frames. The reason of such choice is that each frame has invalid parts, which corresponds to only partly illuminated areas by the real antenna beam. Used overlapping scheme allows to create a stitched panoramas without gaps in the real flight conditions when the SAR platform can be quite instable [2].

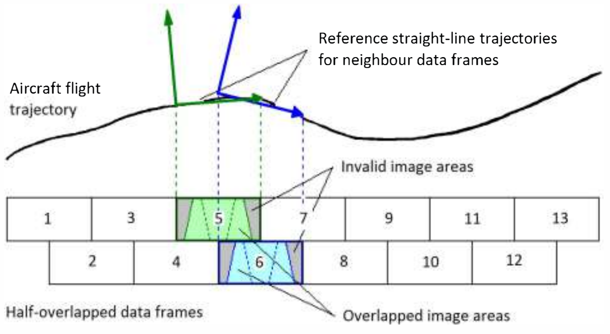



Figure 1. SAR processing with data frames.

A common way to perform the stitching of SAR frames is to compensate the rotation component based on the relative frame orientation with subsequent estimation of unknown two-dimensional translation component (linear shifts in two directions on the ground plane). The rotation angle is determined by the aircraft velocity vector components which are measured by the navigation system. As for the linear shifts, they can be estimated via cross-correlation of SAR frames. In order to eliminate the influence of the bright scatterers and make the cross-correlation peak sharper, we propose to apply the high-pass filter to the input images before the correlation evaluation. Fig. 2 contains an example of two adjacent SAR frames obtained by the RIAN-SAR-X system produced at the Institute of Radio Astronomy [7].

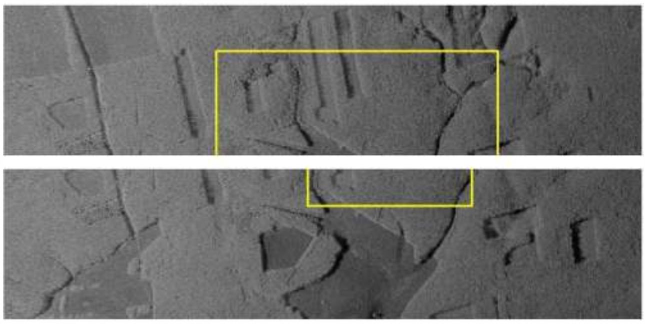


Figure 2. Example of SAR frames pair.

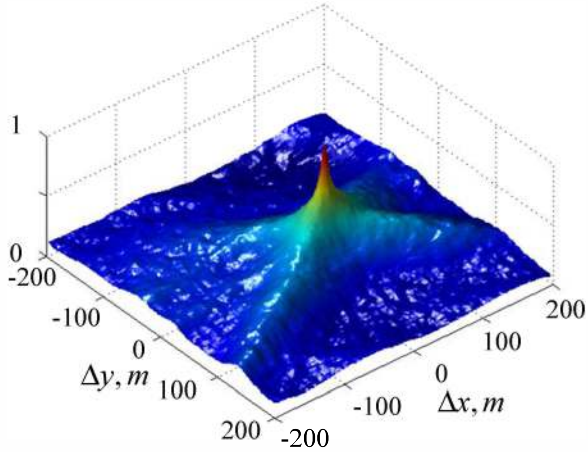
The high-pass filtering can be accomplished in a simple way by performing of Gauss smoothing of an input image and subtraction of smoothed component from the initial image

$$I_{LF}(i,j) = \sum_{n=-Mw}^{Mw} \sum_{m=-Mw}^{Mw} W_G(n,m) I(i+n, j+m), \quad (1)$$

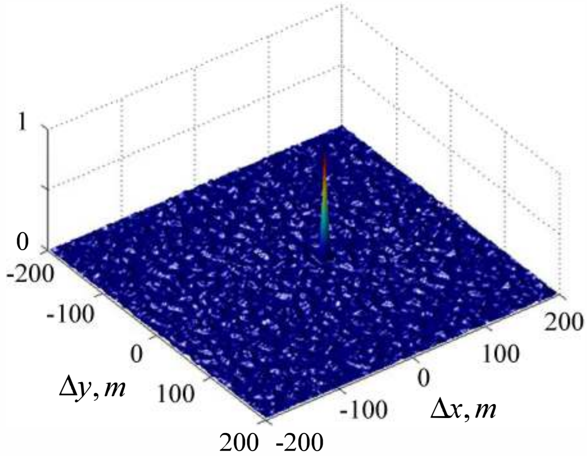
where $Mw = Nw/2, W_G$ is a Gaussian kernel, $Nw$ is a size of Gaussian kernel. The preprocessed image is determined as

$$I_{HF}(i,j) = I(i,j) - I_{LF}(i,j). \quad (2)$$

The effect of the image preprocessing is illustrated in Fig.3. One can see that the cross-correlation peak becomes sharp and well noticeable after preprocessing (Fig. 3b). This makes the estimation of its position more reliable and accurate.




(a)




(b)

Figure 3. Calculated cross-correlation functions
(a – initial images, b – preprocessed images).

In order to make the frame stitching more system independent, we propose to incorporate the SURF algorithm [8] for this purpose. This method is known as one of the most widely used local feature descriptors applied for various computer vision problems. The idea of the technique is based on 3 basic steps: keypoints detection, description and matching. In general, image pixels are considered as keypoints if they demonstrate high gradient level with respect to the local neighborhood [8]. It was shown that Hessian-based keypoint detectors demonstrate good repeatability and stability [8]-[9]. As for the keypoints description, SURF algorithm uses 4 Haar based features [10] calculated in 16 quadrants around the keypoint. Obtained 64-dimensional vector is called the SURF descriptor.

Considering a pair of SAR frames the sequence of keypoints can be detected and corresponding descriptors are constructed. In order to increase the performance one can consider the keypoints matching problem within the patches of adjacent SAR frames. Fig. 4 illustrates an example of descriptors matching.

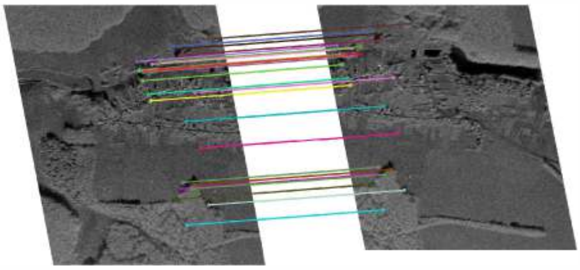


Figure 4. Matched pairs of keypoints.

The matching is accomplished based on the Euclidean distance metrics

$$d_E = \left( \sum_{i=1}^{64} (u_i - v_i)^2 \right)^{1/2}, \quad (3)$$

where $u_i, v_i$ are corresponding elements of keypoints descriptors. A straightforward approach for keypoints matching is the brute force method [9], which calculates the distances for all descriptors combinations and returns the smallest one. In order to filter out incorrect matches several important rules are applied. In particular, the matching threshold should be carefully chosen for rejecting of matches with distances $d_E$ larger than a threshold $d_E^{th}$. Secondly, repeated descriptors should be filtered out as well. Such situation can arise in the case of images with self-similar structures. Finally, based on filtered keypoints pairs it is possible to reconstruct an unknown affine transformation between the images. Two possible options for the parameters estimation can be applied. The first is to choose 3 best keypoints pairs and evaluate 3 unknown parameters (rotation angle and 2 linear shifts). The second option is to estimate the parameters of geometrical transformation using least-squares fitting for remaining amount of keypoints pairs.

The proposed solution does not depend on the navigation system measurements and allows to estimate unknown shifts and rotations automatically from SAR frame pairs.

## III. AUTOMATICAL ROAD LOCATION METHOD

The data extraction from obtained SAR images is a separate challenge [4]. It includes such tasks as automatical road location [11]-[12], target detection and texture segmentation [13], etc. In the paper we concentrate on a problem of extraction of the road segments from SAR images.

An important thing is that roads have few distinctive features. In particular, the width of the road is almost constant. Also the road pixels demonstrate an intensity gradient with respect to the local neighborhood. Finally, road pixels intensity is quite low [12] (Fig. 5).

The idea of the developed method is based on the two- step extraction algorithm. At first, the stroke width transform (SWT) [14] is applied on the input SAR image. The idea of the method is based on the analysis of gradient directions within the image edge map.

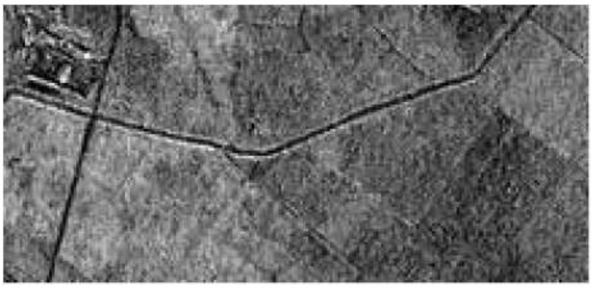


Figure 5. Input SAR image with road segments.

In order to apply the SWT, at first, the horizontal and vertical Sobel gradients [9] are calculated. This is accomplished via the convolution of input image with Sobel kernels (3*3 kernel example)

$$G_x^{Sobel} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \ G_y^{Sobel} = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}. \quad (4)$$

Based on introduced gradients, one can easily evaluate the full intensity gradient and its direction as follows

$$G_I^{Sobel} = \sqrt{\left(G_x^{Sobel}\right)^2 + \left(G_y^{Sobel}\right)^2}, \ \varphi = \mathrm{atan}\left(\frac{G_y^{Sobel}}{G_x^{Sobel}}\right). \quad (5)$$

The idea of SWT is quite straightforward. For each pixel in the Canny edge map [15] we analyze the gradient direction (Fig. 6a). For each edge pixel $p$ we follow the ray $r = p + nd_p$ until the edge pixel $q$ is not found. If the $d_q$ (gradient direction) is roughly opposite, each pixel of output image with stroke widths along the direction along the segment $[p, q]$ is assigned to the width $|\vec{pq}|$.

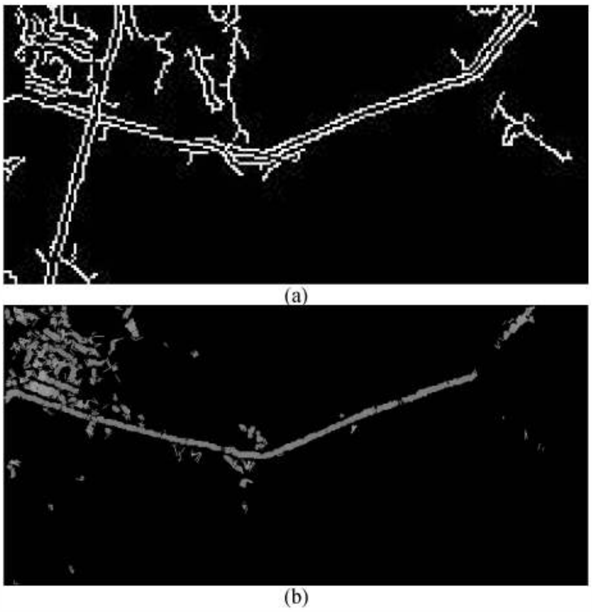


Figure 6. Edge map and stoke width images
(a – Canny edge map, b – stroke width image)

As a result, the stroke width image can be obtained (Fig. 6b). One can observe that not all road segments are seen in this image. Due to existence of the speckle noise in SAR images, the gradient direction is changing drastically in some areas, which results in decreasing of SWT performance.

In order to improve the road detection capability, we propose to utilize the contour detection techniques [9] in the developed algorithm. The problem is that the applied contour extraction procedure can result in detection of other image areas, which should be properly filtered out. In order to accomplish this, we propose to use the two-dimensional gradient histogram (Fig. 7). In particular, we reject the pixels with low gradient intensity values and leave only few main directions of the gradient. At the last step, the Hough transform is applied within the detected contours for the filtered pixels which results in the successive road location. Fig. 8 illustrates the detected road segments.

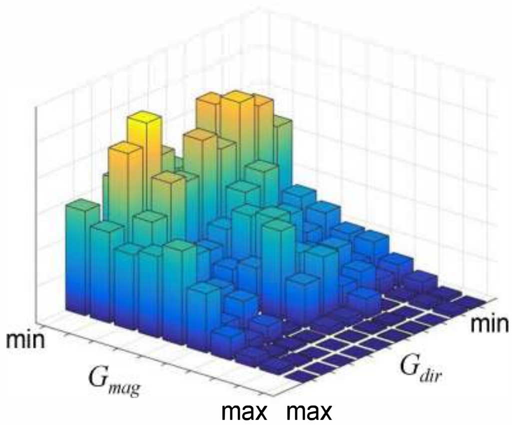



Figure 7. Two-dimensional gradient histogram.

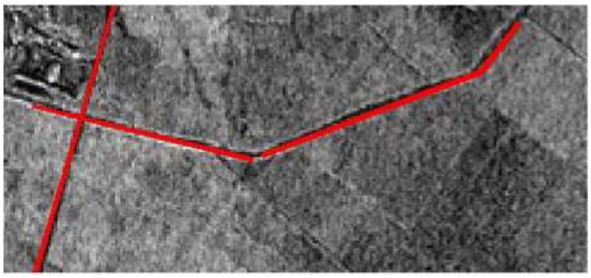


Figure 8. SAR image with detected road segments.

Extracted roads can be used for such purposes as navigation applications and image stitching tasks. Recently we have shown that the estimated road coordinates can be also utilized for the evaluation of moving target parameters using a single-antenna SAR system [11].

## IV. Conclusion

In the paper, two important applications of computer vision for SAR imaging tasks are considered. It is shown that usage of SURF descriptors matching allows to perform the stitching of the radar image frames without priory information about the reference frames orientation. Also an efficient algorithm for the automatical road location based on SWT and contour analysis is developed. Obtained results can be a basis for other remote sensing applications including moving target parameters estimation, object classification etc.

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