Experimental results: In our experiments, the primary aim was to test the performance of the indexing key hiding rather than the precision of image retrieval. To this end, a small database of around 10000 images in BMP format was established by subjecting each image to those processing stages specified in Fig. 1. As JPEG compressors have variable quality settings and these settings can affect the resolution of the quantisation matrices used to compress the images, we chose two representative settings, 70 and 100, to implement our experiments, which cover the normal range most commonly used in practice. In principle, the major impact upon the information hiding by those settings is that the encoded watermarks are more visible for lower quality settings since those high frequency components are ignored. However, since our approach incurs very little change upon those DCT coefficients, further experiments showed that the reconstructed image quality remains good even at lower settings.

Table 1 summarises our experimental results on indexing key hiding for all the images inside our database, which are mainly illustrated in average figures. The results show that the watermarks are virtually indistinguishable, with excellent PSNRs. The watermark (256 bytes) cost is also very good, only 54 bytes and 18 bytes for quality settings of 70 and 100, respectively. This translates as a key compression of between 79 and 93%. As the storage cost for indexing keys is 2.5 mb for 10000 images, our savings achieved by the proposed approach are 1.97 and 2.325 mb for the two quality levels tested.

Table 1: Summary of experimental results

Quality setting	PSNR (dB)	MSE	JPEG encoded size (bytes)	Watermark encoded size (bytes)	Difference in bytes
70	37.25	3.50	4171.26	4171.35	54.09
100	53.93	0.52	11820.74	11820.44	17.70

Conclusions: We hence described an efficient approach to hide the indexing keys inside the JPEG compressed images via digital watermarking technology. This approach proved to have a number of advantages, which include: (i) storage space required for indexing keys is reduced to the region of 7–21% of that required by uncompressed keys; (ii) the quality of reconstruction at the decoding end remains almost unchanged; (iii) the computing cost incurred is ignorable compared with the existing JPEG compression; (iv) significant potential exists for more data hiding since only the four DCT coefficients are involved inside each block and the number of blocks is fixed at 512. Therefore, further research can be carried out to investigate the possibility of embedding more indexing keys as digital watermarks inside the compressed images.

It may seem that the data hiding approach could affect efficiency since the indexing keys need to be recovered from the compressed codes. Considering the fact that: (i) the key hiding only involves the first four DCT coefficients of each block, (ii) recovering the indexing keys only requires entropy decoding (no IDCT); and (iii) even a partial decoding proves to be a negligible overhead compared with full decompression [14], the effect upon the indexing efficiency, if any, would be negligible.

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J. Jiang (*Department of Electronic Imaging & Media Communications, School of Informatics, University of Bradford, Bradford, BD7 IDP, United Kingdom*)

A. Armstrong (*School of Computing, University of Glamorgan, Pontypridd, Wales, CF37 IDL, United Kingdom*)

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Multi-model SAR image despeckling

Cheng Wang and Runsheng Wang

A multi-model despeckling approach for SAR image is presented. The chi-squared test is used to segment the image into homogeneous and heterogeneous regions. Then, the heterogeneous regions are separated into subregions, each of which consists of the points with same edge orientations. Homogeneous regions and the separated subregions are despeckled according to their characteristics. Experimental results are reported.

Introduction: In SAR images, the presence of speckle contaminates the radiometric and textural information. Many speckle-reducing filters have been developed based on different statistical descriptions of speckle. Based on the multiplicative noise model, Lee [1] deduced a speckle-reducing filter. McConnell *et al.* [2] developed a global optimal MAP filter for the gamma statistical model. Although these filters work well for homogeneous scenes, they become unstable in textured regions. It is more reasonable to use different speckle descriptions for different kinds of regions due to the complex signal-dependent nature of the speckle. Many researchers present their filter based on this ideal. Lopes *et al.* [3], for example, segments the SAR image into different regions according to simple local statistics, and uses different filters in different regions. Walessa *et al.* [4] introduces the GMRF model to describe the texture, and designs a corresponding despeckling method. In their algorithms, the choice of the model corresponds to a parameter estimation problem. The filter suffers from the aperture problem and heavy computation consumption.

This Letter presents a new multi-model speckle-reducing approach. First, the image is segmented into homogeneous and heterogeneous regions. Then the heterogeneous regions are separated into subregions according to the edge orientation. All the regions are filtered according to their characteristics. There are two major improvements to the previous research. First, the chi-squared test, instead of the commonly used coefficient of variance (COV), is used to give a more effective segmentation of the homogeneous regions. Second, the heterogeneous regions are separated into the subregions, where the pixels have the same edge orientation. This segmentation introduces more global information, and involves less computation.

Segmentation of homogeneous regions: In the homogenous regions, such as farm fields and water surfaces, the speckle is fully developed, so that the first order statistical distribution of the speckle in SAR image can be expressed as a gamma distribution.

We separate the SAR image into gamma-distributed homogeneous regions and the more fluctuant heterogeneous regions. First, the statistical measurement of each image cell is calculated to form a new measurement image. Then a global threshold is used to segment the measurement image.

The coefficient of variance (COV = standard deviation/mean) is often used as the measurement. Since only the local deviation and the local mean are involved, the COV is insufficient to describe the local situation, and leads to an unreliable segmentation. In our approach, the chi-squared test is utilised to segment the image. It tests whether the observation can be regarded as randomly drawn from the expected gamma distribution or not. Denoting fi as the observed frequency (obtained within the neighbourhood as considered pixel), and Fi as the expected frequency (calculated from the gamma distribution with the local parameters), the test criterion is:

$$\chi^2 = \sum_{i=1}^{k} \frac{(fi - Fi)^2}{Fi}$$

χ^2 provides a quantitative description of the discrepancies between the observed frequency and the expected gamma frequency. Given a rejection level, if χ^2 is greater than the corresponding cumulative distribution, then the observation is viewed as coming from other distributions. More statistical information is introduced in χ^2 than COV. Consequently, the segmentation based on χ^2 is better.

Segmentation of heterogeneous region based on edge orientation: The heterogeneous region is critical for the interpolation of the image. The information within the heterogeneous region is expressed as many structures, which can be considered as the regular group of edge points. Owing to the existence of the speckle, the regularity of the structures is uncertain on a small scale. The former algorithms increase the size of the neighbourhood to improve the estimation of the regularity. This causes an increase in computational consumption. Another problem is that the neighbourhood is round or square; the bigger the size, the more probably different patterns are included inside the neighbourhood.

In our approach, the heterogeneous region is separated into subregions, each of which is a set consisting of connected points with a similar edge orientation. There is no limitation on the expansion of the subregions, so more global information can be included than that in the former descriptions. Each subregion is despeckled according to its characteristics. The segmentation is carried out in two steps. First, the edge orientation and the edge magnitude of the pixels all through the heterogeneous region are calculated. Then the connected points that have similar edge orientation are grouped to form the subregions.

i) *Edge operator:* In this Letter, we use a combined edge operator. The edge magnitude is calculated by the ratio edge operator, since it is CFAR in SAR image; and the edge phase (the vertical of the edge orientation) is calculated by the Canny edge operator, since it is accuracy for phase.
ii) *Grouping of points:* First the connected points that have similar edge orientation are grouped. Then a hierarchical connection is performed to overcome the break caused by the heavy speckle.

The resultant attributes of the subregions include the coordination of the points and the edge magnitude distribution within the subregion.

Different filters for different kind of regions: Within the homogeneous regions, the intensity is gamma-distributed. Much research has been performed based on the gamma statistical model. We choose McConnell's MAP filter to filter the speckle in homogeneous regions.

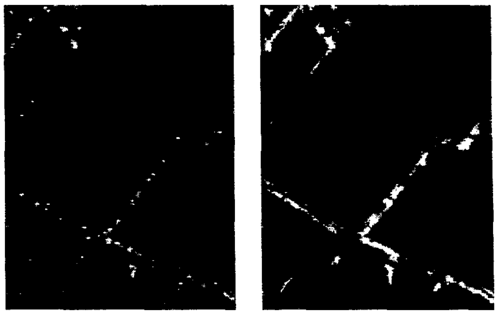
Within a subregion of the heterogeneous region, the pixels have similar edge orientation. That is to say, in the image, each of the subregions corresponding to a curve that has a small curvature. Tangentially to the curve, the intensity should be continuous. The task of despeckling is equivalent to maintaining this continuity. We use a modified median filter to do this job.

First fit the subregion with a thrice curve. Then perform a $1D$ median filter along the tangential orientation. The intensity value in the centre pixel is updated by

$$p' = \lambda p + (1 - \lambda) M(D)$$

where p is the intensity value, $M(D)$ is the median along the tangential orientation D, and λ is the parameter in direct proportion to $\mathrm{Var}(D), 0 < \lambda < 1$. The modified median filter is iterated 3–5 times.

A strong scatterer has a point-like appearance, and cannot be modelled as either homogenous regions or the line-liked subregions of heterogeneous region. We preserve them separately. The strong scatterers are detected and removed before the segmentation, and are put back into the resultant image at last.



a b

Fig. 1 Original image and results of filter
a Original X SAR image
b Result of proposed filter

Experiments and discussion: We apply the proposed filter on an X-band airborne SAR image, and some synthetic SAR images. The result is shown in Fig. 1. To give sufficient comparison, further quantitative evaluations are performed. The proposed filter and some well-known filters are applied to simulated images. The ENL (equivalent number of looks) of the resultant images and the variance of the difference (VOD) between the original image and the filtered images are listed in Table 1. The ENL is calculated within homogeneous terrains and the VOD is considered throughout the whole image.

Table 1: Comparison of filters with ENL and VOD (intensity values range from 0 to 30.0)

	ENL	VOD
Original image	6.542	0
Lee filter	32.345	3.526
McConnell filter	65.325	2.121
Proposed filter	65.325	1.97

The above experiences demonstrate that the proposed approach adequately smoothes out the speckle in the homogenous region, and preserves texture information in heterogeneous regions at the same time.

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Cheng Wang and Runsheng Wang (*ATR Lab, School of Electronic Science and Engineering, National University of Defense Technology, Changsha, Hunan, P. R. China*)

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