Speckle suppressing based on morphological filter and fuzzy logic

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A novel morphological filtering algorithm is proposed for suppressing speckle noise in images. The algorithm employs directional morphological close-open and open-close operations, then computing the membership of the filtered versions' every pixel according to the designed fuzzy rule. The final filtered image is composed of all the pixels with corresponding maximal membership. The validity of the algorithm is demonstrated.

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Speckle reduction is becoming a commonly used routine process in laser radar images, synthetic aperture radar (SAR) images and ultrasonic images. As a consequence, a number of filtering algorithms dealing with speckle noise have been proposed. In these techniques, morphological methods have attracted a lot of attention, several morphological filters for reducing speckle noise have been developed, such as the F. Safa's algorithm[1], and weighted morphological filter[2], etc, and have also been applied for SAR speckle reduction. In this paper, we construct a speckle noise suppression scheme based on directional morphological filter and fuzzy logic. A comparison is made in speckle noise suppression ability on our filter scheme, and the notable Lee's filter[3], F. Safa's algorithm, weighted morphological filter, and concluding remarks are given.

The morphological filters with two-dimensional (2D) morphological openings and closings or closings and openings, are not well adapted to the speckle case. This is due to the high variability of the speckle and to 2D character of the structuring element. Even a 3×3 structuring element may contain one or several very sharp maxima or minima, so that an opening or a closing with respect to this element modifies the local value noticeably. To some degree, these drawbacks can be avoided by using linear structuring elements. Thus, our filter scheme uses the structuring elements p of a certain size in several directions $u_1, u_2, \cdots, u_n$ in morphological opening and closing. In considerations of speckle noise removal and detail preserving abilities, one kind of useful structuring element shown in Fig. 1 is proposed.

Let $X(n)$ denote input image and $Y(n)$ denote output image. Directional morphological filter is defined as

$$Y(n) = [X(n) \circ B^{pu_i}] \bullet B^{pu_i},$$
$$Y(n) = [X(n) \bullet B^{pu_i}] \circ B^{pu_i}, \quad (1)$$

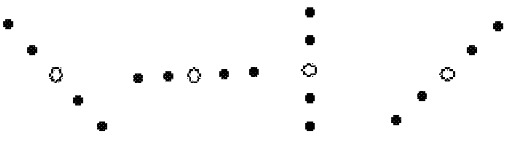

Fig. 1. 5 points 4 directional linear structuring elements.

where $\circ$ and $\bullet$ denote morphological opening and closing operation, respectively, B^{pu_i} is structuring element with length p and direction u_i, X is employed morphological opening-closing operations and closing-opening operations with respect to 5 points 4 directional linear structuring elements, respectively, and the eight filtered versions are acquired as

$$Y_i(n) = [X(n) \circ B^{pu_i}] \bullet B^{pu_i}, p = 5, i = 1,2,3,4,$$
$$Y_j(n) = [X(n) \circ B^{pu_i}] \bullet B^{pu_i}, j = i + 4. \quad (2)$$

The more directions taken, the more details of images will be preserved, but at the expense of a degradation of speckle noise removal ability. In consideration of speckle noise removal ability, fuzzy logic will be applied.

One of the key features of fuzzy logic is its ability to deal with the typical uncertainty, which characterizes any physical system. In fact, fuzziness really affects many aspects of an image process: input signal can be noisy and incomplete. A new inference mechanism using speckle noise removal will be presented here.

Let the directional morphological filtered results $Y_i(n)$ be a digitized input signal. Let $X_n = X(n)$ be the noisy signal at position n, and let $W(n) = \{X_i\}$ be the set of neighboring samples, which belong to a window centered on X_n. Let $m(n)$ be the mean of all elements of window $W(n)$.

The input variables of the fuzzy system are defined as the differneces between the amplitude and the mean given as

$$S(n) = Y_i(n) - m(n). \quad (3)$$

Because speckle-imaging model follows $X(n) = Z(n) + v(n)Z(n)$, where $X(n)$ and $Z(n)$ are noisy and ideal signal, respectively, and $v(n)$ is a random variable with mean of zero and variance of σ_v^2, the smaller the absolute difference between amplitude of the pixel and mean of pixels in the filtering window, the higher the membership of the pixel. Thus the fuzzy set can be based on the following rules:

If the absolute difference between amplitude of the pixel and the mean is very large (e.g. larger than σ

which is the standard variance of the amplitude in window $W(n)$), then the membership of the pixel is very low.

If the absolute difference between amplitude of the pixel and the mean is very small (e.g. smaller than the σ), then the membership of the pixel is very high.

Therefore, we use triangular-shaped fuzzy set by one parameter u for the purpose of reducing speckle noise: here u represents the width of the fuzzy set, and u can be associated with the standard variance σ. In particular, we adopt three fuzzy sets labeled small (SM), medium (ME), and large (LA) as shown in Fig. 2, for the purpose of reducing speckle noise and image enhancement. There, $|v| \geq |u|$. While the mean is small, fuzzy set labeled SM in Fig. 2 is adopted, where the negative difference ($S(n)$) has higher membership than the corresponding positive one. While the mean is large, fuzzy set labeled LA in Fig. 2 is adopted, which the positive difference ($S(n)$) has higher membership than the corresponding negative one.

According to these fuzzy sets, we can estimate the membership $C_{Y_i}(n)$ of $Y_i(n)(i = 1, 2, \cdots, 8)$ with respect to the filtering window $W(n)$. The fuzzy membership of every pixel is computed in the eight filtered visions. Then in the directional morphological filter, the output is modified as

$$\widetilde{Z}(n) = Y_I(n) \text{ with } \mathrm{Max}[C_{Y_i}(n)],\ i = 1, 2, \cdots, 8. \quad (4)$$

In some circumstances, $\widetilde{Z}(n)$ may coincide with all $Y_i(n)(i = 1, 2, \cdots, 8)$. However, in the presence of speckle noise, the probability of coincidence will be very low. The output $\widetilde{Z}(n)$ can therefore be expected to remove the speckle noise more effectively while edges are preserved.

The performance of the proposed filter scheme is compared with that of Lee filter, F. Safa algorithm and weighted morphological filter. The original image of size 271 x 404 (8 bits per pixel) is showed in Fig. 3(a). The image in Fig. 3(b) is corrupted by speckle noise. The image in Fig. 4(a) is MSTAR (moving and stationary target acquisition recognition) data. The images restored by the notable Lee filter, F. Safa algorithm, and the weighted morphological filter are showed in Figs. 3(c), (d), (e) and Figs. 4(b), (c), (d), respectively. A 5×5 square window is chosen for both Lee filter and the weighted morphological filter. The images restored by the proposed filter scheme are shown in Fig. 3(f) and Fig. 4(e). Then, Performance of various filters including Lee's filter, F. Safa's algorithm, weighted morphological filter and the proposed filter scheme is examined through speckle-index[4] and normalized mean square error (NMSE)[5]. The measured results are shown in Table 1. The restored images show that Lee's filter and weighted morphological filter cannot preserve the geometrical features of images, and the measured results show that the speckle noise suppressing performance of the proposed scheme is superior to that of F. Safa's algorithm, weighted morphological filter, and nearly the same as that of Lee's filter.

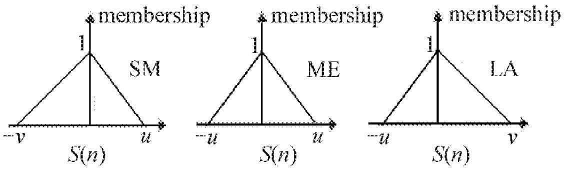

Fig. 2. Definition of triangular-shaped fuzzy set.

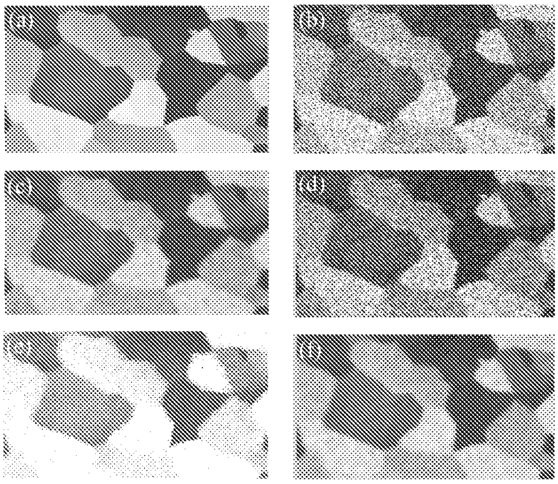

Fig. 3. (a) The original image; (b) noise image; (c) the image filtered by Lee's filter; (d) the image filtered by F. Safa's algorithm; (e) the image filtered by weighted morphological filter; (f) the image filtered by the proposed filter scheme.

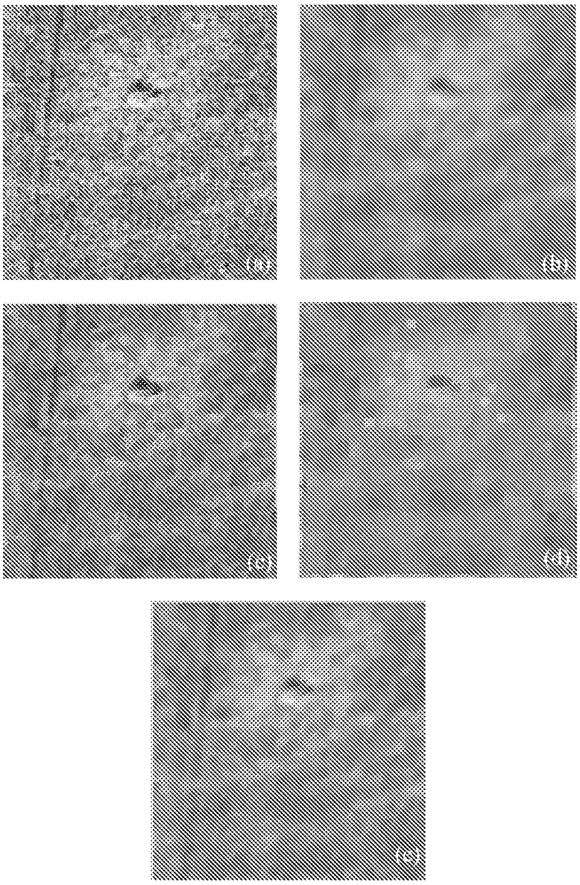

Fig. 4. (a) Noisy image; (b) the image filtered by Lee's filter; (c) the image filtered by F. Safa's algorithm; (d) the image filtered by weighted morphological filter; (e) the image filtered by the proposed filter scheme.

Table 1. Speckle-Index and NMSE of Noisy Image and Processed Image

Noisy Image and Algorithm	Speckle-Index	NMSE	Speckle-Index/MSTAR
Noisy Image	0.3032	0.0795	0.1625
The Proposed Filter Scheme	0.0382	0.0043	0.0364
Lee's Filter	0.0417	0.0056	0.0358
F. Safa's Algorithm	0.2159	0.0617	0.0961
Weighted Morphological Filter	0.0688	0.1534	0.0438

We have presented a new filtering scheme based on morphological filter and fuzzy logic for reducing speckle noise in image. Experimental results show the filter scheme cannot only suppress speckle noise more effectively but also preserve the geometrical features of images. Through comparison, it is proved that the filter scheme is superior to Lee's filter, F. safa's algorithm, weighted morphological filter, although slightly more computation is required.

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