Image noise level estimation based on affine reconstruction and noise sample histogram

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Abstract: An image noise level estimation method was presented by using affine reconstruction technique and the calculated noise sample histogram. The watershed-based image segmentation was firstly utilized to divide the noisy image into several homogenous blocks. Then by applying affine reconstruction technique, the noiseless affine image signal and the noise residual image were obtained. Noise samples for the standard deviation values of each segmented patch were calculated from the noise residual image. After that the histogram of estimated noise samples was described to find out the specific noise level interval with the most noise samples falling into. Finally, the image noise standard deviation was computed by the average of noise samples in the selected noise interval. Experiments are implemented to demonstrate the effectiveness of the proposed algorithm. The presented method could produce accurate and reliable estimation results for images with rich textures and edges.

Key words: image noise estimation; image segmentation; affine reconstruction; noise samples histogram

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基于仿射重建和噪声散点直方图的图像噪声水平估计

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摘　要: 结合信号仿射重建技术和图像噪声散点直方图,提出了一种图像噪声水平估计方法。首先,对于输入的噪声图像,采用基于分水岭的图像分割算法,将其分为若干像素均匀的图像块。采用仿射信号重建算法,实现无噪声的仿射图像信号和噪声余量图的分离和获取。从噪声余量图中计算获取各图像分块的噪声散粒点, 每个散粒点表示各个图块的噪声标准差大小。随后, 统计噪声散粒点直方图, 进而确定最多散粒点分布的噪声强度区间。最终的图像噪声标准差估计值由该选择区间内的所有散粒点标准差均值计算得到。对比实验表明,算法能够进行准确可靠的图像噪声水平估计,对于细节和边缘丰富的图像效果优异。

关键词: 图像噪声估计; 图像分割; 仿射信号重建; 噪声散点直方图

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0 Introduction

Image noise is the most common but unpleasant image distortion along with the image chain of many imaging systems, such as remote sensing imaging, microscopy imaging, monitoring imaging, etc. It occurs in the process of image capture, transmission, restoration and storage[1]. Therefore, an effective image noise estimation method is necessary to help evaluate and improve the quality of the impaired images. Normally, noise is always assumed as the distribution of additive white Gaussian noise[2]. Many researches have been carried out to focus on the problem of estimating the noise level from a single image without any reference images.

Multi-scale transforms are effective tools to implement image noise estimation, such as wavelet transform[3-5]. The noise level is measured according to the subband coefficients after transforming the noisy image into the frequency domain. Besides, filter-based approaches are very popular to extract the flat image signal by convolving the noisy image with a certain designed low-pass filter[6]. Then image noise level could be calculated from the difference of noisy image and the filtered image. Moreover, block-based noise estimation algorithms are also widely used to segment the image into amount of homogeneous image patches[7-8]. The uniform image blocks are used to estimate the signal and noise levels. Furthermore, recently several excellent noise estimation approaches have been presented to realize more robust noise level estimation. Liu et al. proposed the automatic noise estimation from a single noisy image[9]. The noise level function is introduced to illustrate the real noise distribution as a function of image brightness. Jiang and Zhang utilized the degree of image features measured based on statistical hypothesis tests in order to present a fast and reliable noise estimation algorithm for additive white Gaussian noise[10]. Pyatykh et al. proposed an effective and accurate principal component analysis(PCA) based noise level estimation method by analyzing image blocks containing only textures[11]. Liu et al. also applied the PCA analysis techniques to select weak textured image patches and presented a patch-based noise level estimation algorithm[12]. Although various noise estimation approaches were proposed, novel accurate image noise level estimation framework is still the hot research direction to be applied in many fields.

So as to realize accurate image noise level estimation, in this paper an image noise estimation method is presented by using affine reconstruction and noise sample histogram to deal with the additive white Gaussian noise. The image segmentation algorithm is firstly utilized to divide the image into several homogenous blocks. By using the affine reconstruction technique, the noiseless image signal is obtained. Then the image residual is worked out combined with the input noisy image and the reconstructed noiseless image signal. The standard deviation values of each segmented patch are calculated to illustrate the histogram of noise samples so as to find out the specific noise level interval with the most noise samples falling into. Finally, the estimated image noise level is obtained by the average of noise samples in the selected histogram interval. The flowchart of the algorithm is illustrated in Fig.1.

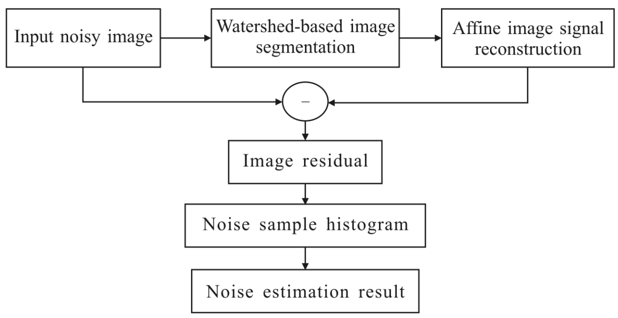


Fig.1 Flowchart of the presented algorithm

1 Affine image reconstruction

In order to implement effective image noise estimation, the crucial process is to separate the signal and noise components from the input noisy image. In our algorithm, an affine signal reconstruction model is introduced in order to reconstruct the affine image, which is treated as the noiseless signal component.

For the input image patch J, the affine image reconstruction model could be expressed as the following optimization problem:

$$M'=\arg\min_{M}\sum_{\psi\in G}\|J(\psi)-M[\psi^{T}\ \ 1]^{T}\|^{2} \tag{1}$$

where $J(\psi)$ is the pixel value of J, ψ is the coordinate variable and M represents the affine matrix. The solution of Eq.(1) is to find out the optimal affine matrix. It can be written as the following expression for short as C replaces the part of $[\psi^{T}\ \ 1]^{T}$ to stand for the coordinate matrix of the input image:

$$M'=\arg\min_{M}\|J-MC\|^{2} \tag{2}$$

In order to solve the minimization problem in Eq.(2), we set the derivative of M' as zero, then the optimal M is obtained with the form as

$$C^{T}MC-C^{T}J=0 \tag{3}$$

where C^{T} is the transposed matrix of the coordinate matrix C.

With the help of the least squares solution of the optimal approximation problem in linear algebra, the optimal affine matrix is finally computed. As the optimal approximation problem of matrix function is expressed as

$$\|HTK-B\|_{F}=\min \tag{4}$$

The least square solution of T can be written as the form

$$T=H^{+}BK^{+} \tag{5}$$

where H^{+} and K^{+} are the generalized inverse matrixes of H and K. According to this solution method, the optimal affine matrix M' can be computed as

$$M'=(C^{T})^{+}(C^{T}J)C^{+} \tag{6}$$

where $(C^{T})^{+}$ and C^{+} stand for the generalized inverse matrix of C^{T} and C, respectively.

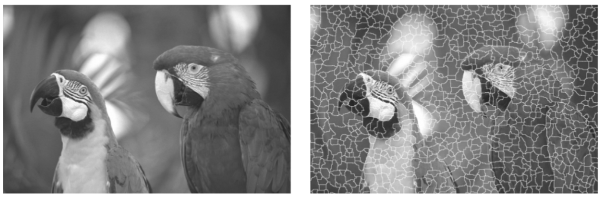
Accordingly the affine reconstruction image signal is reconstructed by multiplying the optimal affine matrix M' by the coordinate matrix C as

$$J_{signal}=M'\times C \tag{7}$$

The aim of the optimal solution for Eq.(1) is to obtain the noiseless affine image signal from the input noisy image. By effective and smart solving process, the affine reconstruction result is acquired to help carry out accurate noise level estimation framework.

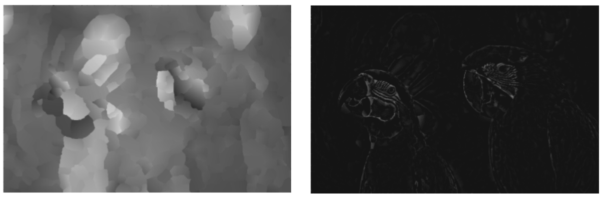
2 Image noise level estimation

In this section, the implementation details of the proposed noise estimation algorithm are introduced. In this paper, we deal with the noisy image in gray scale. An example of the presented noise estimation method is shown in Fig. 2. In this example, a noisy image with additive white Gaussian noise is input to test the performance of the method, which is shown in Fig.2 (a). The process results of the presented framework are illustrated in Fig.2(b)-(c), respectively. The details would be explained in the following sections.



(a) Original noisy image (Added Gaussian noise standard deviation is 0.0117 and the estimated noise standard deviation is 0.0118)

(b) Watershed segmentation result



(c) Affine image signal reconstruction result

(d) Residual image

Fig.2 An example of the presented image noise level estimation method

2.1 Watershed-based image segmentation

Image segmentation is an effective way to select homogenous patches of the image in order to estimate the noise level. In our algorithm, the watershed-based image segmentation algorithm[13] is used to divide the noisy image into several blocks with similar size. Watershed segmentation algorithm treats the image as a "topographic map". The adjacent image block is segmented by the "catchment basins" and the "dividing lines". Therefore, the original noisy image J in Fig.2(a) is completely segmented into the image patch set as expressed:

$$J=U_i J_i,\ i=1,2,\cdots,m \tag{8}$$

where $J_i I J_k=\phi$ when $i\neq k$. m is the total number of the segmented patches. The segmented image is illustrated in Fig.2(b). The parameter η of the segmented algorithm, which is set to tune the patch size, is selected as 2 to determine the proper segmentation size.

2.2 Image residual

For each image patch obtained in Section 2.1, the pixel intensity is considered as the similar level. In order to calculate accurate noise level, the affine reconstruction process introduced in Section 1 is utilized to the segmented image patches so as to extract the image signal. The image signal reconstruction result is referred to J_{signal}, which represents the uniform signal map of all of the segmented image blocks, as shown in Fig.2(c). It can be seen from Fig.2(c) that the noiseless signal image patches are obtained effectively.

After the procedure of image reconstruction, the estimated image residual could be calculated from the difference between the input noisy image J and the reconstructed image signal J_{signal}, as shown in Fig.2(d), which is expressed as

$$J_{\text{residual}}=J-J_{\text{signal}} \tag{9}$$

2.3 Histogram of the estimated noise samples

Following the above mentioned algorithm steps, the standard deviation values of each image patch in the residual image are computed from J_{residual} to obtain the estimated noise standard deviation set $\{\sigma_i\}$, where $i=1,2,\cdots,m$. m is the total number of the segmented patches mentioned in Section 2.1. For the estimated noise sample set $\{\sigma_i\}$, the values contain both the real noise component and subtle texture variation. A proper estimated value is expected to be selected from the set by the histogram of the estimated noise samples.

The calculated noise standard deviation values distribute over a wide range. The entire range is divided into several small uniform intervals, with the value interval length as 0.005. Then the numbers of estimated noise samples belonging to each section are counted. Accordingly, the histogram of the estimated noise samples for Fig.2(a) is illustrated in Fig.3 to show the distribution of numbers in each interval.

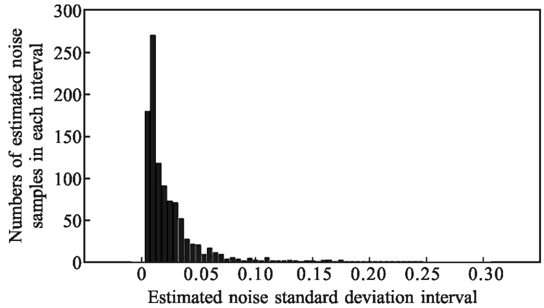


Fig.3 Histogram of the estimated noise samples

2.4 Final noise estimation

Afterwards, the interval with the most samples falling in is chosen. For the noisy image example in Fig.2 (a), the noise sample interval is set as 0.005. According to the histogram distribution of the estimated noise samples in Fig.3, the selected noise level interval is [0.010,0.015]. The final image noise standard deviation estimation is obtained by the average of estimated noise values belonging to the selected interval. For the noisy image in Fig.2 (a), the added Gaussian noise standard deviation is 0.011 7 and the estimated noise standard deviation value from Fig.3 is 0.011 8.

3 Experimental results and discussion

An image noise estimation example is shown in Fig.2, with the estimated noise value in the image caption.

Moreover, a couple of experiment images are also used to test the performance of the proposed approach, which are illustrated in Fig.4. The estimation

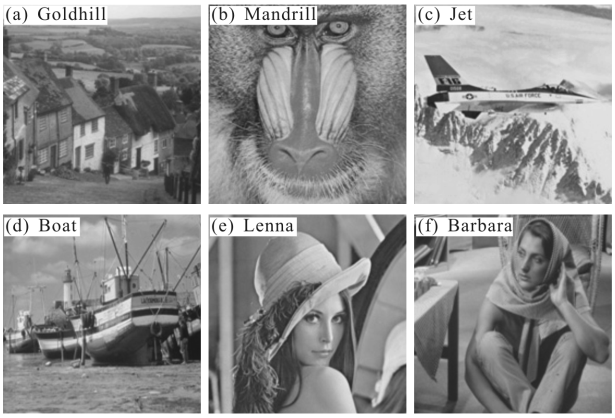
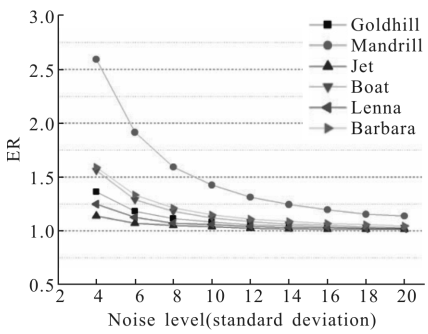


Fig.4 Test images with the size of 512×512

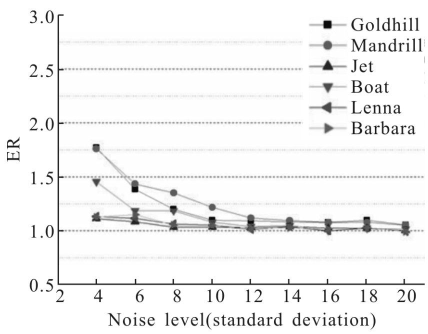
ratio (ER)[14] is used to measure the accuracy of the noise estimation method, which is defined as the following

$$ER=\frac{\sigma_{\text{estimated}}}{\sigma_{\text{added}}} \tag{10}$$

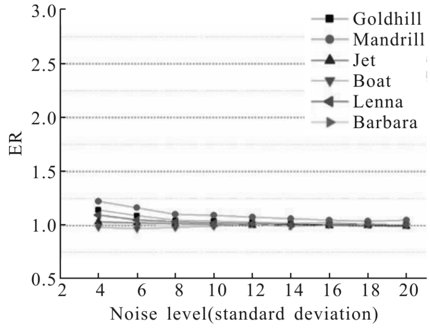
where $\sigma_{\text{estimated}}$ and σ_{added} are the estimated and added white Gaussian noise standard deviation values. We compare the proposed noise estimation method with other three excellent methods[15-16,11]. The ER results of the compared algorithms for the tested images are shown in Fig.5.



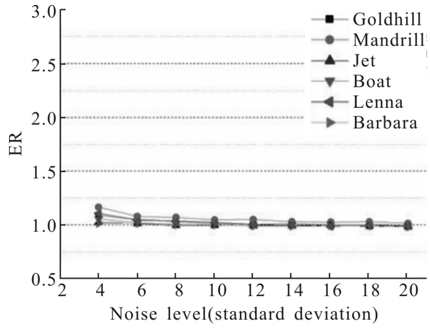
(a) Method in Ref.[15]



(b) Method in Ref.[16]



(c) Method in Ref.[11]



(d) Proposed method

Fig.5 Estimated ratio results

For perfect noise estimation, ER evaluation values should be 1 for all different noise levels. From Fig.5 we can see that the results obtained by Ref.[15] and [16] are relatively inaccurate among the low noise level range. The estimation errors tend to decrease as the noise level becomes higher, but still not so good. While the proposed method achieve the close performance result compared with the excellent noise estimation approach in Ref.[11]. ER values are small for the whole noise level range.

Besides, another two evaluation indexes are calculated to test the estimation error. The mean value and the variance value of the estimation errors are expressed as

$$\mu_{\varepsilon}=\frac{\sum_{i=1}^{Num}\varepsilon(i)}{Num} \tag{11}$$

$$\sigma_{\varepsilon}^{2}=\frac{\sum_{i=1}^{Num}(\varepsilon(i)-\mu_{\varepsilon})^2}{Num-1} \tag{12}$$

where Num is the total number of the tested images. In our experiment, Num=6; $\varepsilon(i)$ is the absolute estimation error between the true and the estimated noise standard deviation, which is computed as $\varepsilon(i)=|\sigma_{estimated}-\sigma_{added}|$. The evaluation result is shown in Tab.1 and Tab.2.

Tab.1 Estimation error mean values with different noise levels

Noise δ (standard deviation)	4	6	8	10	12	14	16	18	20
Ref.[15]	2.33	1.92	1.62	1.44	1.30	1.17	1.09	0.98	0.88
Ref.[16]	1.57	1.35	1.17	0.88	0.63	0.75	0.52	0.82	0.46
Ref.[11]	0.39	0.36	0.31	0.30	0.29	0.26	0.23	0.20	0.24
Proposed method	0.35	0.48	0.26	0.25	0.25	0.34	0.15	0.18	0.24

Tab.2 Estimation error variance values with different noise levels

Noise δ (standard deviation)	4	6	8	10	12	14	16	18	20
Ref.[15]	3.68	2.86	2.15	1.70	1.36	1.14	0.92	0.73	0.71
Ref.[16]	1.34	0.65	0.79	0.37	0.21	0.12	0.25	0.31	0.18
Ref.[11]	0.11	0.12	0.08	0.12	0.11	0.10	0.09	0.06	0.03
Proposed method	0.14	0.12	0.14	0.12	0.14	0.07	0.04	0.06	0.05

It is easy to conclude from Tab.1 and Tab.2 that compared with the two methods in Ref.[15] and [16], the proposed noise estimation approach obtains smaller estimation error mean values and variance values for the whole noise level range. It has a superior evaluation performance. As to the comparison with the method in Ref.[11], the evaluation results are similar and both the mean values and the variance values of the estimation errors are at a low level, which demonstrates that our presented approach reaches the similar noise level estimation error with the advanced designed algorithm proposed in Ref.[11] and could provide accurate image noise estimation.

4 Conclusion

In this paper, an image noise estimation approach is presented for the additive white Gaussian noise, combined with the affine reconstruction model and the histogram of noise samples. After the image segmentation process, the affine image signal of each image patch with similar size is obtained with affine reconstruction technology. Then the residual image is computed from the difference of the input noisy image and the signal image in order to calculate the standard deviation value of each block. Finally, the noise standard deviation level is estimated by the average of the selected interval from the noise sample histogram with most number of noise samples within the range. Experiments are carried out to show the accurate and reliable performance of the proposed approach.

The future work is to focus on the speed up the program to apply the method on the real-time image system.

References:

[1] Pan J, Yang X, Cai H, et al. Image noise smoothing using a modified Kalman filter [J]. ***Neuro Computing***, 2016, 173 (P3): 1625-1629.

[2] Tian J, Chen L. Image noise estimation using a variation-adaptive evolutionary approach [J]. ***IEEE Signal Processing Letters***, 2012, 19(7): 395-398.

[3] Donoho D L, Johnstone J M. Ideal spatial adaptation by wavelet shrinkage [J]. ***Biometrika***, 1994, 81(3): 425-455.

[4] Starck J, Murtagh F. Automatic noise estimation from the multiresolution support [J]. ***Publications of the Astronomical Society of the Pacific***, 1998, 110(744): 193-199.

[5] Yang J, Wang Y, Xu W, et al. Image and video denoising

using adaptive dual-tree discrete wavelet packets [J]. ***IEEE Transactions on Circuits & Systems for Video Technology***, 2009, 19(5): 642–655.

[6] Yang S M, Tai S C. Fast and reliable image-noise estimation using a hybrid approach [J]. ***Journal of Electronic Imaging***, 2010, 19(19): 3007.

[7] Uss M, Vozel B, Lukin V. Image informative maps for estimating noise standard deviation and texture parameters[J]. ***Eurasip Journal on Advances in Signal Processing***, 2011, 2011(1): 1–12.

[8] Shin D H, Park R H, Yang S, et al. Block-based noise estimation using adaptive Gaussian filtering [J]. ***IEEE Transactions on Consumer Electronics***, 2005, 51(1): 218–226.

[9] Liu C, Szeliski R, Bing K S, et al. Automatic estimation and removal of noise from a single image [J]. ***IEEE Transactions on Pattern Analysis & Machine Intelligence***, 2008, 30(2): 299.

[10] Jiang P, Zhang J Z. Fast and reliable noise estimation algorithm based on statistical hypothesis tests [C]//Visual Communications and Image Processing, IEEE, 2012:1–5.

[11] Pyatykh S, Hesser J, Zheng L. Image noise level estimation by principal component analysis [J]. ***IEEE Transactions on Image Processing A Publication of the IEEE Signal Processing Society***, 2013, 22(2): 687–699.

[12] Liu X, Tanaka M, Okutomi M. Noise level estimation using weak textured patches of a single noisy image [C]//IEEE International Conference on Image Processing, IEEE, 2013: 665–668.

[13] Vincent L, Soille P. Watersheds in digital spaces: an efficient algorithm based on immersion simulations [J]. ***IEEE Transactions on Pattern Analysis & Machine Intelligence***, 1991, 13(6): 583–598.

[14] Tai S C, Yang S M. A fast method for image noise estimation using Laplacian operator and adaptive edge detection [C]//International Symposium on Communications, Control and Signal Processing, IEEE, 2008: 1077–1081.

[15] Immerkær J. Fast noise variance estimation [J]. ***Computer Vision & Image Understanding***, 1996, 64(2):300–302.

[16] Liu X, Tanaka M, Okutomi M. Estimation of signal dependent noise parameters from a single image [C]//IEEE International Conference on Image Processing, IEEE, 2014: 79–82.