Research of properties of digital noise in contrast images

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Abstract. The article is devoted to the research of probabilistic properties of digital noise in contrast images. For obtaining numerical characteristics of the additive noise distribution physical experiments were made. These characteristics testify that noise in digital images is non-uniform both on variance and on distribution are received were for this purpose made. The image with contrast overfall from black to white was simulated and the noise filtration is carried out by known methods of smoothing. During a Monte-Carlo method of statistical tests it was established that smoothing based on the generalized method of the least absolute values eliminates noise on contrast overfall more efficiently.

Keywords: Digital noise, contrast image, filtration, smoothing, characteristics of noise, the generalized method of the least absolute values.

1 Introduction

Now digital photo and video devices practically forced out analog devices. Despite a number of advantages, digital images formation devices are not ideal and they also have errors of measurements as any metering device. As a result the created image consists of the useful image and digital noise in the form of the imposed mask from pixels of casual colour and brightness. Various models use at the description of digital noise and models of the additive, pulse and multiplicative noise are the most widespread.

Upgrading of the digital image is one of the most important problems of digital processing of images. It is solved generally by means of the methods of suppression of digital noise based on algorithms of a filtration of images. It is solved generally by means of the digital noise suppression methods based on algorithms of a filtration of images. However, despite variety of algorithms of digital filtration, they as a rule have heuristic character. Probably, poor research of digital noise properties in contrast images is the main reason.

Many authors specify that noise distribution in digital images submits to the Gaussian distribution law. Therefore, algorithms of suppression of noise which well work for a normal distribution are offered, and majorities of such algorithms are the linear. However use the linear digital filters for noise suppression in contrast images leads to

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a blurring of details contours of contrast images that reduces sharpness of the image and, therefore, worsens quality. Application of non-linear algorithms of noise suppression on the basis of the median filtration offered by John Tukey [4] for contrast images is ineffective, because median filters are sensitive to jump in brightness on the image. Various modifications of a median filtration [5–7] in some cases reach a prize in comparison to a simple median filtration, but they are insufficiently formalized, and usually demand existence of padding prior information. In [8] was offered to use for a filtration of contrast images non-linear smoothing on the basis of the generalized method of the least absolute values (GMLAV). The particular positive effect was reached, but also conditions for efficient application of a method are not clear.

Thus, it is possible to note that for contrast images models of digital noise, which adequacy is not rather investigated, are used. It leads to an inefficiency of the developed algorithms of a digital filtration, their serviceability for separate classes of images without establishment of the reasons of it.

The purpose of the article is research of probability properties of digital noise in contrast images and check on effectiveness of some known methods of noise suppression at a filtration of contrast images.

2 The research part

We will consider for a start a question as noise in digital images behaves. Value of noise depends from characteristics of the digital camera sensor: type, production technology, density of placement a separate photosensitive element. There are two main production technologies of digital arrays. It is CCD and CMOS. Different modern photo sensors and also new development, like Foveon x3 and similar, are based on the CCD or CMOS technology. At the moment distribution of digital sensors based on the CMOS technology much higher and makes about 90% of all let-out products therefore the emphasis will be put on the sensors made on this technology.

Also noise level is influenced by the light sensitivity parameter determined by the ISO standard. If the ISO parameter increases, more noise will be present on the digital image. However this parameter influences noise level in the image, but not on the law of its distribution more.

Photon noise has the greatest impact on a noise of digital photos. This noise is a consequence of the discrete nature of light. In case of the ideal not rustling telecamera it is sensitivity depends on photon noise only – fluctuations of number of photons of rather mean value. Owing to independence of photons in light flow the quantity of photons in an expansion element in a specific frame is subordinate to Poisson statistics [10].

Therefore, the noise distribution law will be defined more by a type of a digital sensor and photon noise, to a lesser extent other parameters.

We will make experiment. We will use the digital reflex camera which photo sensor is made on the CMOS technology, for obtaining input data, necessary for the analysis. The image of the monotonic areas of different brightness (Fig. 1) printed on photographic paper of the A4 size will serve as object of shooting.

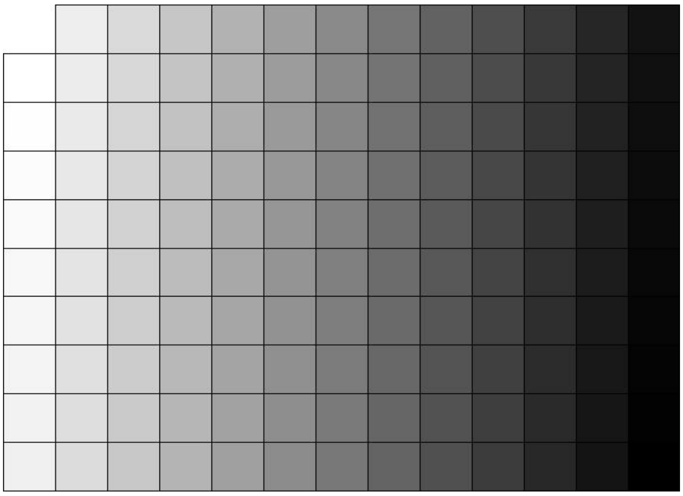

Fig. 1. Test image.

Having made photographing, we will receive the digital image. For some simplification we will use not the colour image, but the gray scale image that will give us 256 possible values of brightness of pixel where is "0" a black colour, and "255" – white. From the received image we will select a quantity of areas: the most dark, the lightest and the intermediate.

As a result we created 9 areas of different brightness (Fig. 2). As areas were made from the same image, the parameters influencing value of noise are identical.

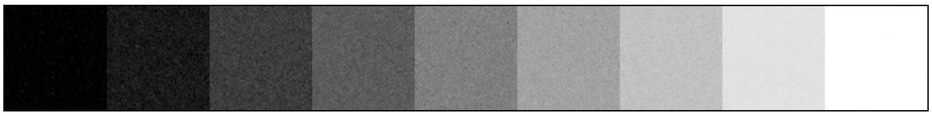

Fig. 2. Areas with different brightness level.

Digital noise in the image represents shift of pixel's brightness towards increase or decrease concerning the true actual value. As a matter of convenience we will consider some areas of the different brightness (Fig. 3) at increase.

The size of such area is 100x100 of pixels that gives us the sample of 10000 values. For each sample, we will calculate the following characteristics: mathematical expectation (m.e.), variance, values of skewness and excess coefficients (tab. 1). We will take theoretical mathematical expectation which we would receive for a reference point, having the ideal digital camera.

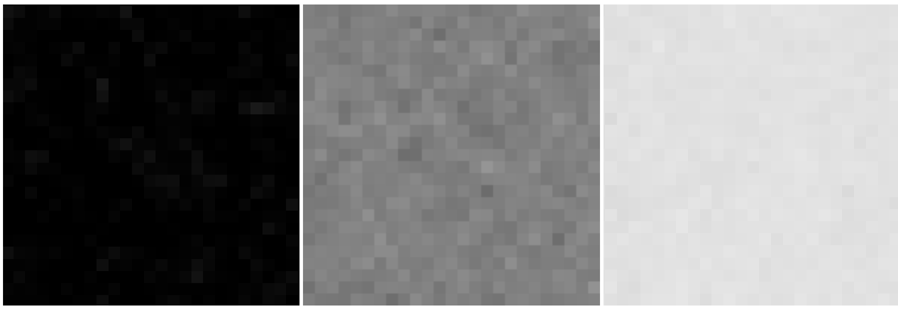

Fig. 3. Areas with different brightness level at increase.

Table 1.

Theoretical m.e.	0	32	64	96	128	160	192	224	255
m.e.	2,58	25,40	60,69	91,52	127,76	161,91	193,55	225,72	254,64
Variance	13,08	64,47	63,80	46,66	43,77	26,96	15,34	3,56	0,23
Skewness coefficients	2,353	0,034	-0,148	-0,031	-0,124	-0,148	-0,206	-0,189	-0,604
Excess coefficients	8,790	0,559	0,545	0,438	0,450	0,379	0,431	0,369	-1,620

With increase in a brightness of image variance becomes less that is the variation of pixel's brightness decreases, therefore, noise level decreases.

In Fig. 4 pixel's distribution of rather useful signal of the darkest area (at the left) and the lightest area (on the right), and also the gray area is shown (in the middle). On the lightest area noise variance much less, than on dark area of the image therefore in this case noise is characterized by brightness deviation on 1-2 values concerning the true value.

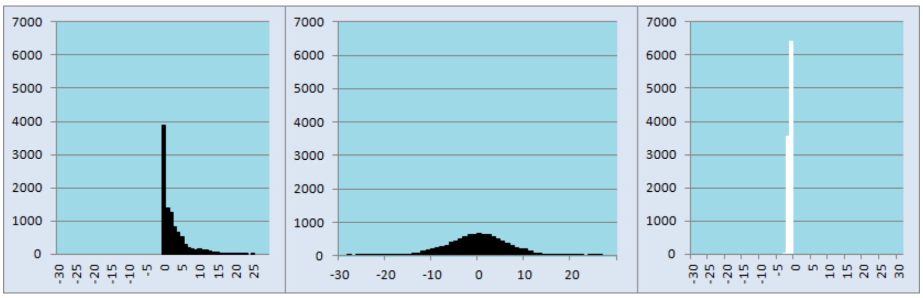

Fig. 4. Pixel's distribution of rather useful signal of the darkest area (at the left), the lightest area (on the right) and the gray area (in the middle).

Variance in the darkest area and in the lightest is beaten out from the common tendency. It occurs because pixel's brightness can't overstep the bounds of admissible values and noise distribution arising near limit of values 0 and 255 is limited to the limiting values. Pixels which brightness in case of a normal distribution on a dark area would have to leave abroad zero and would have the negative values, accept brightness equal 0. The same is typical for the light area: all values of brightness which at a normal distribution would have size larger 255, accept value 255, as illustrates Fig. 4.

The received distributions in the cases approached to boundaries of admissible values of brightness are not normal as for cases 0 and 255 (tab. 1). Skewness and excess coefficients considerably differ from null. Distribution is gradually normalized in case of a distance from boundaries of black and white colours.

In the received results some sharp brightness emissions which are not typical for the general nature of distribution were found. They appeared owing to defect in pixels (photosensitive elements on a matrix). These emissions can be described as an impulse noise. However the number of similar emissions is not enough, 2 from 17915904. Strictly speaking, faulty pixels on a matrix speak about defect of the device and are not a constant component of noise. As the number of similar emissions is not enough, the pulse component of noise in digital images can be neglected. As the number of similar emissions is not enough, the pulse component of noise in digital images can be neglected.

Multiplicative noise is a multiplication of a signal to some value. It has to be shown more on light areas of the image. However on actual data the similar is not traced. Noise variance decreases as approaching light areas, and not vice versa, as assumes a multiplicativity.

Thus, we found out the noise emergence mechanism in digital images. Noise variance on dark areas of the image is much higher, than on the light. Moreover, moving from areas with the 0 level of brightness to areas with a brightness is slightly higher than average, variance sluggishly decreases, but at a further moving to bright areas variance decreases sharply and at boundary of the maximal brightness becomes 10 times less. We observe obviously non-linear decrease of noise variance. And noise distribution on boundaries of brightness sharply differs from the normal.

Further we investigate effectiveness of three various digital filters when smoothing the image with contrast overfall in the form of sharp transition from black to white by Monte-Carlo method of statistical tests. We use the linear averaging, the median filter and smoothing on the basis of GMLAV as digital filters. We will set an aperture equal 5 for all filters.

Let's simulate $M = 1000$ samples of $n = 50$ values (pixels) imitating to jump in brightness from dark to light, considering the distribution laws of noise received above on dark, light and gray areas of the image. Average distribution from the M simulated samples is specified at Fig. 5 from the left and random distribution for one sample is specified from the right.

Average distribution on the M experiments is specified at Fig. 6-8 from the left and random distribution for one sample after a filtration by one of three methods is specified from the right (Fig. 6 – the linear averaging, Fig. 7 – median filtration, Fig. 8 – smoothing on the basis of GMLAV).

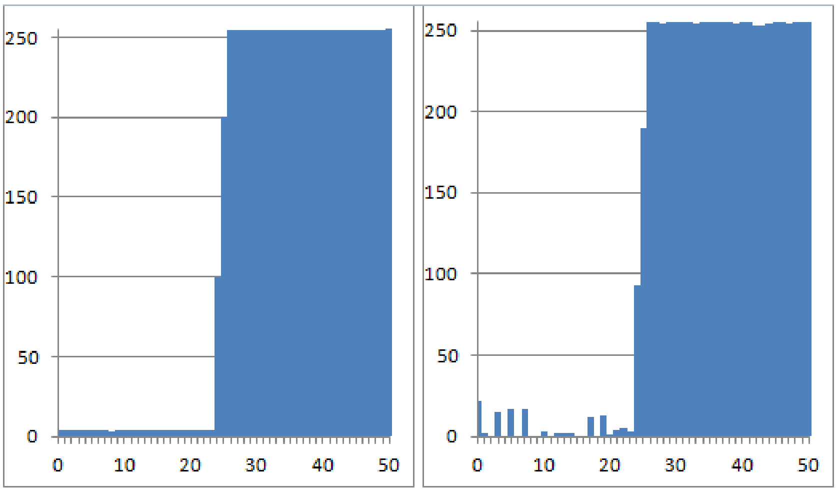

Fig. 5. The diagram of brightness for the simulated samples.

Now we will smooth the received samples by three filters: the averaging filter, the median filter and the filter on the basis of GMLAV. For all filters we will set an aperture equal 5. For the filter on the basis of GMLAV we use function of a look [9]:

$$\rho(x) = \mathrm{arctg}(|x|)$$

After a filtration we receive the following diagrams of distribution of brightness:

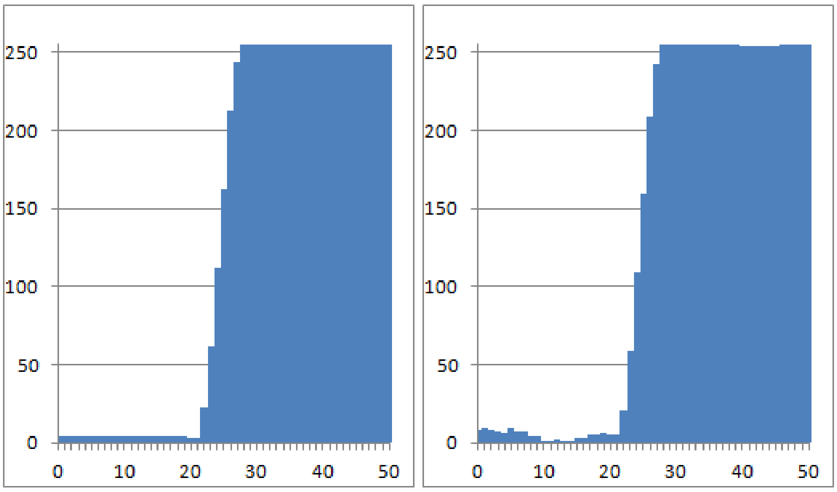

Fig. 6. The diagram of brightness after a filtration by means of averaging.

When using averaging, the spreading on values in comparison to input dates became more expressed that worsens boundary of white and black.

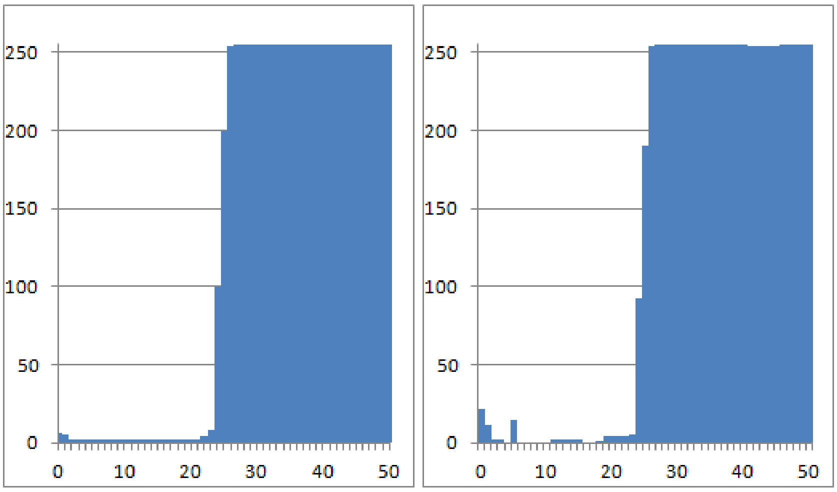

Fig. 7. The diagram of brightness after a median filtration.

The median filter coped with a task much better, however, contrast transition from black to white remains indistinct in the same degree, as at initial model operation.

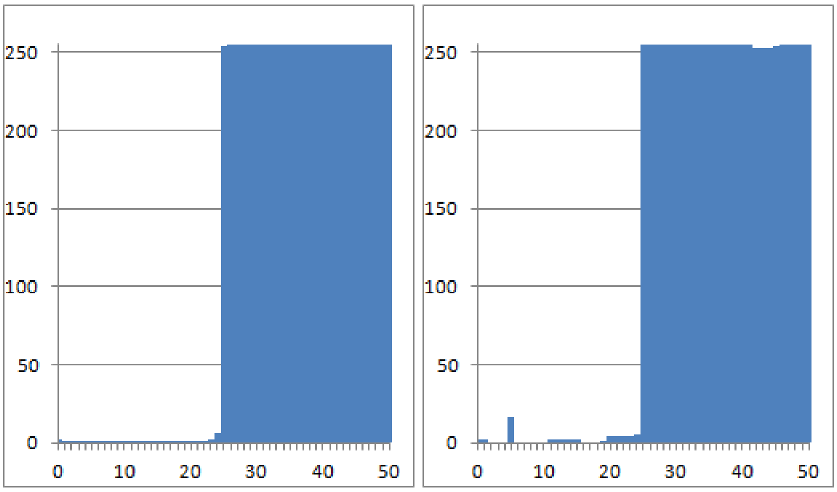

Fig. 8. The diagram of brightness after smoothing on the basis of GMLAV.

The received selection after OMNM filtration is characterized with more sharp boundary. Sharpness of boundary between black and white colour in comparison to initial data above.

For an assessment of smoothing effectiveness we will compare the received values of initial model operation and values after a filtration to an ideal case on a Monte-Carlo method and we will construct 95% confidence intervals for each case (Fig. 9).

We build 95% a confidence interval for the M selective variances for the received results

$$S_{m,i}^2 = \frac{1}{n}\sum_{k=1}^{n}(y(k) - \hat{y}_m^{(i)}(k))^2,$$

where $M = 1000$, $n = 50$, $m=1,2,\ldots,M$, i – a type of smoothing ($i=0$ – the initial noisy image, $i=1$ – the image after the linear averaging, $i=2$ – the image after a median filtration, $i=3$ – the image after smoothing on the basis of GMLAV), $y(k)$ – k-th pixel of the ideal image (contrast overfall without noise), $\hat{y}_m^{(i)}(k)$ – k-th pixel after a filtration.

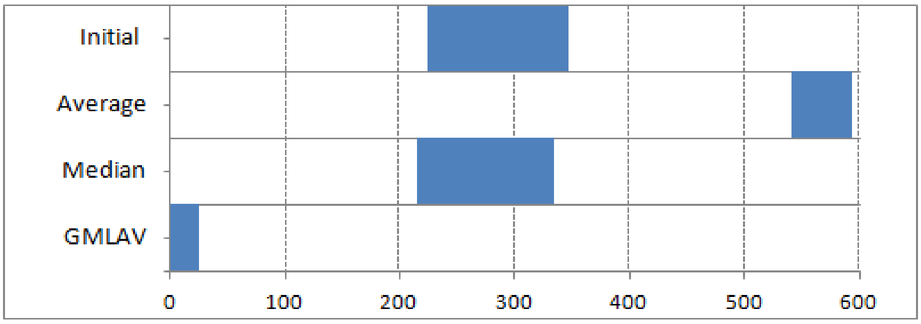

Fig. 9. A confidence interval for the received values.

From Fig. 9 we see that the confidence interval for a case of averaging is displaced towards increase in comparison to initial model operation. These results from the fact that the averaging disturb contrast boundary and there is a shift error, but at the same time unbiased error decreases. The median gives better result, but unlike the filter on the basis of GMLAV does not allow restoring contrast boundary.

3 Conclusions

1. The process of emergence of the additive noise in digital contrast images has non-linear nature.
2. Non-linear nature of noise emergence leads to a spreading of contrast boundaries at images. Besides the distribution law of noise near limits of contrast images becomes not Gaussian even in a case when the additive noise had a normal distribution.
3. Smoothing on the basis of GMLAV of noisy contrast images has essential advantages in comparison to averaging and a median filtration.

4 References

1. Yaroslavsky, L.P.: Introduction to digital image processing. Sovetskoe Radio Publisher, Moscow (1979).- in Russian
2. Honsales, R., Woods, R.: Digital image processing. Prentice Hall, New Jersey (2008).
3. Huang, T.S., Eklundh, J.-O., Justusson B.I., Nussbaumer H.J., Tyan S.G., Zo-har S.: Two-Dimensional Digital Signal Prcessing II. Transforms and Median Filters. In Huang T.S., (eds.) Springer, Heidelberg (1981).
4. Tukey, J.W.: Discussion emphasizing the connection between analysis of variance and spectrum analysis. Technometrics (3). pp. 191–219 (1961).
5. Abreu, E., Lightstone, M., Mitra, S., Arakawa, K.: A new efficient approach for the removal of impulse noise from highly corrupted images. IEEE Trans. On Image Processing. 5(6), 1012–1025 (1996).
6. Chan, R., Ho, C., Nikolova, M.: Convergence of Newton's Method for a Minimization Problem in Impulse Noise Removal. J. Comput. Math. vol.2, 168–177 (2004).
7. Schulte, S., Nachtegael, M., De Witte, V., Van der Weken, D., Kerre, E.: A fuzzy impulse noise detection and reduction method. IEEE Trans. On Image Processing. 15(5), 1153–1162 (2006).
8. Tyrsin, A. N., Surin, V. A.: Non-Linear Filtering of Images on the Basis of Generalized Method of Least Absolute Values. In Supplementary Proceedings of the 3rd International Conference on Analysis of Images, Social Networks and Texts (AIST), pp. 41-47 (2014).
9. Tyrsin, A.N.: Robust construction of regression models based on the generalized least absolute deviations method. In Journal of Mathematical Sciences 139(3), 6634–6642 (2006).
10. Nikitin, V.V., Cyculin, A.K.: TV in physical protection systems. LETI, S.-Pb., 2001. – in Russian.