

# Novel image detector of fixed-valued impulse noise with high noise intensity

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**Abstract.** Impulse noise is a common noise in digital image processing, which includes the fixed-valued impulse noise and the random-valued impulse noise. A novel method is proposed to detect the fix-value impulse that uses the deviation of slant angle as test object to recognize whether a noise candidate is impulse noise pixel. Distinguishing the average method and medium method, the method uses the new test object to detect the impulse noise. The mathematical model and the detection algorithm of this method are stated and analyzed, and the experiments show the performance of this method under the different circumstance. The biggest advantage of this method is to detect the fixed-valued impulse noise correctly and robustly under the different noise intensity that is up to 0.95.

## 1 Introduction

In the digital image processing [1], one of the key problems is the detection and filtering of noise. Two noise models are often used to analyze the image noise: additive Gaussian noise and impulse noise. The additive Gaussian noise is defined by adding a value with a zero-mean Gaussian distribution to every original image pixel. Impulse noise is another kind of common noise in digital image, which includes fixed-valued impulse noise and random-valued impulse noise. For the fixed-valued impulse noise, also called Salt&Pepper noise, the value of polluted pixel is equal to minimum or maximum of pixel value according to the same probability. Many methods are proposed in the recent years, such as TSM filter [2], MSM filter [3], SBF [4], ROR-NLM [5], SAWM filter [6], and ABDND [7]. In this paper, a new method is proposed to detect the fixed-valued impulse noise, which is effective to detect heavy polluted image especially. Instead of average detection and medium detection, the deviation of slant angle is chosen as a new test object for the noise detection. Therefore we call the new detector as DSA (deviation of slant angle).

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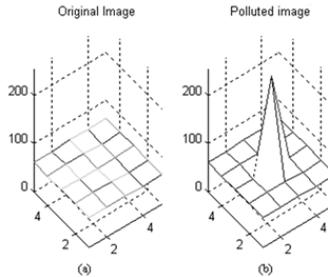
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## 2 Definition of slant angle

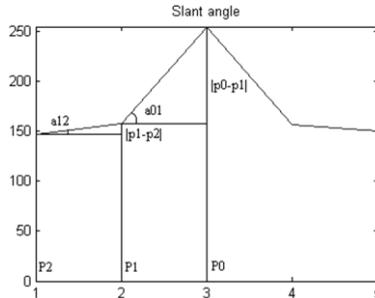
We introduce the noise model simply because many related papers have already described the details of impulse noise. If an image is polluted by the impulse noise, some original pixels are replaced by the noise pixels. If  $x_{ij}$  and  $y_{ij}$  are defined as the pixel value of original image and polluted image at the location  $(i,j)$ , respectively, we define

$$y_{ij} = \begin{cases} x_{ij}, & \text{with probability } 1-p \\ n_{ij}, & \text{with probability } p \end{cases}, \quad (1)$$

where  $p$  is impulse noise ratio,  $n_{ij}$  is the noise value at the location  $(i,j)$  that is independent from  $x_{ij}$ , respectively. If  $n_{ij}$  only equals to the minimum or maximum of pixel value, the noise is called the fixed-valued impulse noise or Salt&Pepper noise. If the noise intensity is low, many detection methods can achieve excellent performance. However, if the noise intensity is very high, such as up to 0.95, it is difficult for most of methods to distinguish between the uncontaminated pixel of which value equals to 0 or 255 and the noise pixel very well.



**Fig. 1.** Simplest polluted scheme with one polluted pixel. (a) Original image. (b) Polluted image.



**Fig. 2.** Definition of slant angle.

In the simplest scene, the center pixel is polluted in a  $5 \times 5$  area while other pixels in this area are normal, which is shown in Fig.1. We can find the left one looks like the plain while the right one looks like the peak in the plain. So the slant angle is a new feature for the fixed-valued impulse noise detection. In Fig.2,  $P_0$ ,  $P_1$ , and  $P_2$  are defined as the center pixel, the neighbor of  $P_0$ , the edge pixel in a  $5 \times 5$  area, respectively. Therefore the slant angles  $a_{01}$  in Fig.3 is defined as Eq.2.

$$a_{01} = \arctan \frac{p_0 - p_1}{D_{p_0 p_1}}. \quad (2)$$

In Eqs.2, we define  $a_{01}$  as the slant angle between  $P_0$  and  $P_1$ ,  $D$  as the distance between  $P_0$  and  $P_1$ ,  $p_0$  is the value of pixel  $P_0$ ,  $p_1$  is the value of pixel  $P_1$ , respectively. Obviously, the value range of slant angle is  $\left(-\frac{\pi}{2}, \frac{\pi}{2}\right)$ . The same to Eq.2, we can also calculate the slant angle between  $P_1$  and  $P_2$  as follows:

$$a_{12} = \arctan \frac{p_1 - p_2}{D_{p_1 p_2}} \tag{3}$$

### 3 Deviation of slant angle

From Fig.1 and Fig.2, we know intuitively the probability that  $P_0$  is a noise pixel is high if the difference between  $a_{01}$  and  $a_{12}$  is large. So the deviation of slant angle can be used for the noise detection. We define the deviation of slant angle in the route  $P_0$ - $P_1$ - $P_2$  as follows:

$$Dev = \left| \arctan \frac{p_0 - p_1}{D_{p_0 p_1}} - \arctan \frac{p_1 - p_2}{D_{p_1 p_2}} \right| \tag{4}$$

It's easy to calculate the distance  $D$  between two pixels. The distance  $D$  between two adjacent pixels is based on the geographic length. We define the distance from a center pixel to an adjacent pixel in its 4-neighborhood is 1 while the distance from this center pixel to an adjacent pixel in its 8-neighborhood except the pixel in its 4-neighborhood is  $\sqrt{2}$ .

Therefore we get the universal expression to calculate  $Dev$  of the route  $i$   $p_0$ - $p_{1i}$ - $(p_{2j}, j \in [1,3])$  as follows:

$$Dev_i = \left| \frac{\arctan \frac{p_0 - p_{1i}}{D_{p_0 p_{1i}}} - \sum_j \arctan \left( \frac{p_{1i} - p_{2j}}{D_{p_{1i} p_{2j}}} \right)}{j} \right|, j \in [1,3] \tag{5}$$

where  $j$  is the number of pixels in the periphery on the route  $i$ . If  $p_{1i}$  has not the adjacent pixels in the periphery on the route  $i$ , that is,  $j$  is zero,  $Dev$  of the route  $i$  is unavailable.

Based on the definition of  $Dev$ , we can compare  $Dev$  with a threshold to distinguish whether a noise pixel candidate is an impulse noise pixel. However, if the noise intensity is high, some of neighbors are also noise pixel probably. Therefore we use some less  $Dev$  values on all routes for the noise detection. DSA is stated as follows.

**Algorithm 1 DSA**

**Stage 1**

Step 1) Convert original image to gray-level image with 8 bit. If the original image is a gray-level image with 8 bit, this step is omitted.

Step 2) Detect all pixel values that equal to 0 or 255 in this gray-level image and mark them as noise candidate, and then go to stage 2.

**Stage 2**

For every noise pixel candidate,

Step 1) Calculation of all available  $Dev$  for every route.

Step 2) Sort all  $Dev$ .

Step 3) Calculation of average on half of all smallest  $Dev$ .

*Step 4) Comparison between mean value and presetting threshold.*

*Step 5) Mark as impulse noise if average is larger than threshold.*

## 4 Experiments

In order to test the performance of DSA, some experiments are tested. We use Microsoft Windows 10 as operation system and Matlab R2009b as the test platform. Two experiments are studied for the performance analysis and comparison. The first experiment is to analyze the performance of DSA, while the second experiment is for the comparison with other state-of-the-art methods.

First experiment is to test the fundamental performance of DSA. Table 1 shows the detection result of Lena under the different noise intensity. The results demonstrate DSA is robust under the different noise intensity, especially in the circumstance of high noise intensity. Table 2 shows the detection details of pepper (0) and salt (255) for Lena under the different noise intensity. The same to Table 1, DSA is also very stable to detect pepper noise pixels and salt noise pixels efficiently in the different circumstance.

**Table 1.** Detection result of DSA for Lena under the different noise intensity (Threshold is  $\pi/12$ ).

Noise Percent	Noise Candidate in Polluted Image	Detected Noise in Polluted Image	Accuracy
10%	26182	24916	95.16%
20%	52339	50733	96.93%
30%	78265	76813	98.14%
40%	104766	103601	98.89%
50%	130975	130053	99.30%
60%	157214	156473	99.53%
70%	183234	182369	99.53%
80%	209522	207559	99.06%
90%	235972	230878	97.84%
95%	249012	240520	96.59%

**Table 2.** Pepper (0) and salt (255) detection details of DSA for Lena under the different noise intensity (Threshold is  $\pi/12$ ).

Noise percent	Pepper (0) candidate in polluted image	Detected Pepper noise	Pepper Detected Accuracy Percent	Salt (255) candidate in polluted image	Detected Salt Noise	Salt Detected Accuracy Percent
10%	13002	12360	95.06%	13180	12556	95.27%
20%	26094	25261	96.81%	26245	25472	97.05%
30%	39149	38383	98.04%	39116	38430	98.25%
40%	52349	51769	98.89%	52417	51832	98.88%
50%	65675	65199	99.28%	65300	64854	99.32%
60%	78227	77850	99.52%	78987	78623	99.54%
70%	91656	91215	99.52%	91578	91154	99.54%
80%	104900	103866	99.01%	104622	103693	99.11%
90%	118220	115564	97.75%	117752	115314	97.93%
95%	124094	120153	96.82%	124918	120357	96.36%

**Table 3.** Comparison of noise detection results for lena with fixed-valued impulse noise.

Noise percent	SBF[4]		ROR-NLM[5]		ABDND[7]		DSA	
	False-Hit	Miss-Hit	False-Hit	Miss-Hit	False-Hit	Miss-Hit	False-Hit	Miss-Hit
10%	0	36	834	1	7	0	0	1266
20%	0	45	731	10	0	0	0	1606
30%	0	112	726	63	0	0	0	1452
40%	0	717	808	577	0	0	0	1165
50%	0	3122	1443	2280	0	0	0	922
60%	0	10949	3441	7335	0	0	0	741
70%	0	29606	7393	20188	0	0	0	865
80%	0	62121	12468	48260	0	0	0	5094
90%	0	111371	12698	92962	0	0	0	8492

In the second experiment we compare the performance between DSA and other 3 methods. Table 3 illustrates the noise detection results of different methods for Lena with the different fixed-valued impulse noise. From this table, we know both the false-hit number (rate) and the miss-hit number (rate) keep in a low level in not only the different image detection but also the different noise intensity. In contrast to DSA, ROR-NLM has not stable performance for different images. SBF is an efficient method when the noise intensity is low (less than 0.5) but has bad performance when the noise intensity is high. ABDND is an excellent method with significant miss-hit rate. But most original pixels whose values are 0 or 255 are detected as the noise pixel in ABDND detection. The performance of DSA is not the most excellent in most of occasions. However, the performance of DSA is very stable in the different image detection and the different noise intensity (from 0 to 0.95). Moreover, when the noise intensity is high, the running times of ABDND and ROR-NLM are very long but the running times of SBF and DSA are short. If the lookup table method is used to calculate the inverse trigonometric function in DSA implementation, the running times of DSA will be shorter so that DSA can be used in the field of real-time application.

## 5 Conclusions

The main contribution of this paper is to propose a new method to detect the fixed-valued impulse noise. Distinguishing from the traditional average methods and medium methods that are widely studied, this method uses the deviation of slant angle for every pixel candidate as the criterion for noise detection. The most advantage of this method is to detect the fixed-valued impulse noise effectively in the circumstance of very high noise intensity (up to 0.95). The experiment results verify this method has good performance under the different noise intensity. This method uses the deviation of slant angle as the test object so that some normal pixels in the edge perhaps are detected as noise pixel. When the method is used for the detection of random-valued impulse noise, the false-hit number should be larger because many normal pixels in the edge are recognized as noise pixel. Therefore this method needs to add some additional criterions for detection of random-valued impulse noise. In a word, this method is a useful method for the detection of fixed-valued impulse noise, especially under the noise pollution with very high noise intensity. The mathematical model, the detection algorithm and the detection object of this method will be studied to expand the application area of this method in the future work.

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