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ОЧИСТКА ИЗОБРАЖЕНИЙ ОТ ИМПУЛЬСНЫХ ПОМЕХ В ДВОИЧНОМ СИММЕТРИЧНОМ КАНАЛЕ СВЯЗИ

CLEANING IMAGES FROM IMPULSE NOISE IN A BINARY SYMMETRICAL CHANNEL

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Аннотация

В работе предложен новый метод очистки незакодированных изображений от импульсных помех в двоичном симметричном канале связи, где при возникновении ошибки, бит информации повреждается и пиксели изображения принимают искаженные значения. Характеристика такого шума соответствует импульсному шуму, где импульсные помехи принимают случайные значения и распределены по изображению случайно. Пиксели определяются как искаженные при помощи оценки разницы между пикселями внутри локального окна. При этой оценке учитывается значение яркостей и удаленность пикселей внутри локального окна. Восстановление изображений выполняется с помощью адаптивной медианной фильтрации.

Ключевые слова: импульсный шум, двоичный симметричный канал связи, медианный фильтр, цифровая обработка изображений, адаптивная фильтрация.

Abstract

The paper proposes a new method for cleaning uncoded images from impulse noise in a binary symmetric channel, where, when an error occurs, the information bit is distorted and the image pixels take incorrect values. The characteristic of such noise cnuorresponds to impulse noise, where impulse noise takes on random values and is randomly distributed over the image. Pixels are determined to be distorted by evaluating the difference between pixels within the local window. This estimate takes into account the brightness value and the distance of pixels within the local window. Image recovery is performed using adaptive median filtering.

Keywords: impulse noise, binary symmetric channel, median filter, digital image processing, adaptive filtering.

Introduction

Images, as one of the forms of information presentation, which are transmitted as messages over communication channels, are subject to interference [1]. When transmitting uncoded images over a communication channel, for example, represented as a model of a binary symmetric communication channel, each bit can be distorted with a certain probability [2]. If at least one bit of the image is distorted, interference occurs that distorts the pixel values. Pixel distortion with a certain probability in a binary symmetric communication channel is similar to impulse noise. Noisy images can negatively affect the operation of various digital image processing algorithms, for example, real-time object recognition, as well as incorrectly display data received from medical or seismological sensors [3].

The problem of restoring an image from impulse noise consists of the problem of finding impulse noise and the problem of restoring a distorted pixel. One of the simple and effective methods for removing impulse noise from images is median filters. But the standard median filter leads to blurring of the image, so modifications of the median filter have been proposed by various authors. One of the modifications that greatly reduced the negative effect of blurring is adaptive median filtering. In adaptive median filters, pixels that are not impulsive noise remain untouched, changes are made only for pixels that have been identified as noisy [4].

The complexity of the pixel detection task depends on the impulse noise model. In the “salt and pepper” impulse noise model, where the distorted pixels take two values: an impulse with minimum and maximum brightness, the detection task is usually not worth it at all. To date, a number of methods for cleaning and detecting impulse noise are known. In [5], a method was developed to clean the image from impulse and Gaussian noise, which is a modification of the bilateral filter for determining distorted impulses. The work [6] describes a method that offers an improvement to the method of [5] and uses a logarithmic function and threshold transformations for this. The paper [7] also describes a comparison of methods [5] and [6] and proposes a method that is another modification of the method [5]. The method introduces a new statistic of the local consensus index, which is calculated by summing up all the similarity values of pixels in its vicinity and finding the value of the central element.

In this paper, we will consider a model for transmitting images through a binary symmetric communication channel (BSC). It will be shown that the characteristics of the noise that occurs in the DSC correspond to the random -valued impulse noise model. The detector of distorted pixels in the image is based on the estimation of the difference between the pixels. Image distortion in a binary symmetric communication channel / distortion of images in a binary symmetrical channel . A channel with a binary input and a binary output, where the probabilities of error and correct transmission are equal, is called a binary symmetric channel. Since each output binary symbol of a channel depends only on the corresponding input binary symbol, we say that this channel is memoryless. Signals can be transmitted via dsk , for example, 0 or 1. Transmission in such a communication channel is not ideal, because of this, the receiving signal with a certain probability p may receive an error, which consists in replacing the sign of 1 with 0 or 0 with 1.

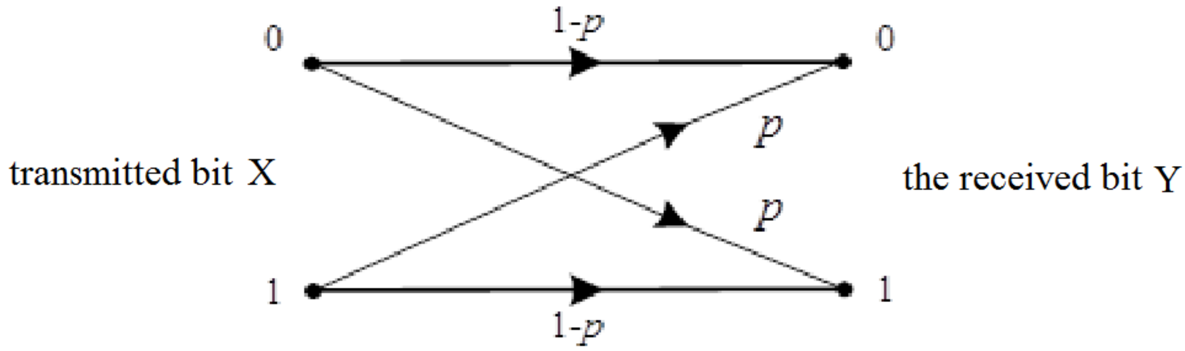


Figure 1. Diagram of a binary symmetrical channel

Figure 1. Shows the DSC scheme p - the probability of error, $1-p$ - the probability of correct transmission.

DSC has input and output signal $X \in \{0,1\}$ and $Y \in \{0,1\}$, hence

$$p(X \mid Y) = \begin{cases} 1-p, & \text{if } X = Y \\ p, & \text{if } X \neq Y \end{cases} \tag{1}$$

Distorted signals in DSC arise as a result of noise. Interference is understood as any random effect on the signal in the communication channel that prevents the correct reception of signals. In communication channels, there are both additive interference, i.e., random processes superimposed on the transmitted signals, and multiplicative interference, expressed in random changes in the channel characteristics.

Additive interference contains three components: concentrated in frequency (harmonic), concentrated in time (impulse) and fluctuation . Impulse interference is a sequence of short-term pulses separated by intervals exceeding the time of transients in the channel. The causes of impulse interference are: the influence of lightning discharges on communication lines; influence of power lines on communication lines; poor contacts in transmission and power equipment; shortcomings in the development and manufacture of equipment; operational reasons, etc. Shortcomings in the development and manufacture of equipment lead to the fact that impulse noise occurs during voltage surges in the supply network or switching from the main elements to the backup ones. Digital data is often transmitted as a sequence of binary numbers (bits of information). During transmission, noise can distort the original message. The model consists of a transmitter capable of sending a binary signal and a receiver.

Data transmission in DSC can be described by the Bernoulli scheme. Let Δ be a random variable that counts the number of failures. Then, according to the Bernoulli scheme, the probability of k errors in the transmission of n bits through the BSC is equal to

$$p(\Delta = k) = \binom{n}{k} p^{n-k} q^{k} \quad (2)$$

where n is the bit depth of the image pixel, p is the probability of distortion of one bit in the DSC. Based on (2), the density of impulse noise in the image in accordance with the bit depth of the image and the probability of bit distortion is

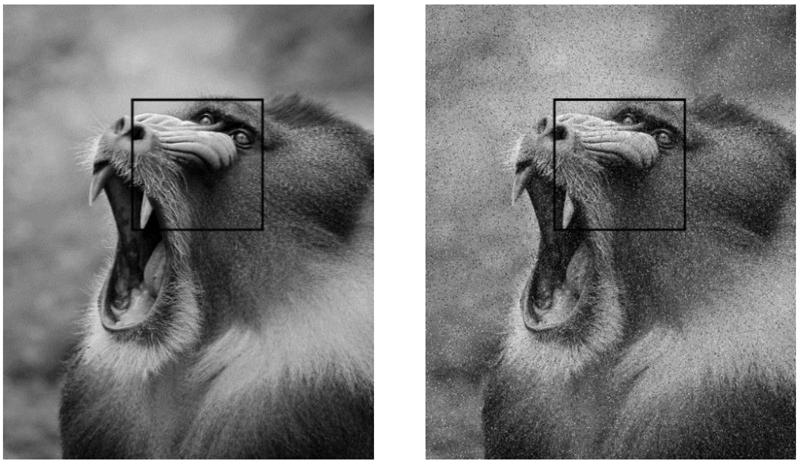
$$\rho = 1 - p^{n-k} \quad (3)$$

Table 1 shows the density of impulse noise ρ in the image in accordance with the probability of bit distortion p.

Table 1. Impulse noise density ρ in the image

Bit distortion probability , p	Pixel bit depth, n			
	eight	12	16	24
0,01	0,077	0,114	0,148	0,214
0,05	0,337	0,4 60	0,560	0,708
0,10	0,570	0,718	0,815	0,920

Consider an image in which errors occurred during transmission through a binary symmetric communication channel. Figure 2 shows a grayscale image where $p = 0.01, 0.05, 0.1$ every bit of the image is likely to be corrupted. The paper presents 8-bit images. The frame highlights the fragments that are considered in the approximation.



a b

Figure 2. Image used in simulation: a) original image; b) distorted image $p = 0,5$;

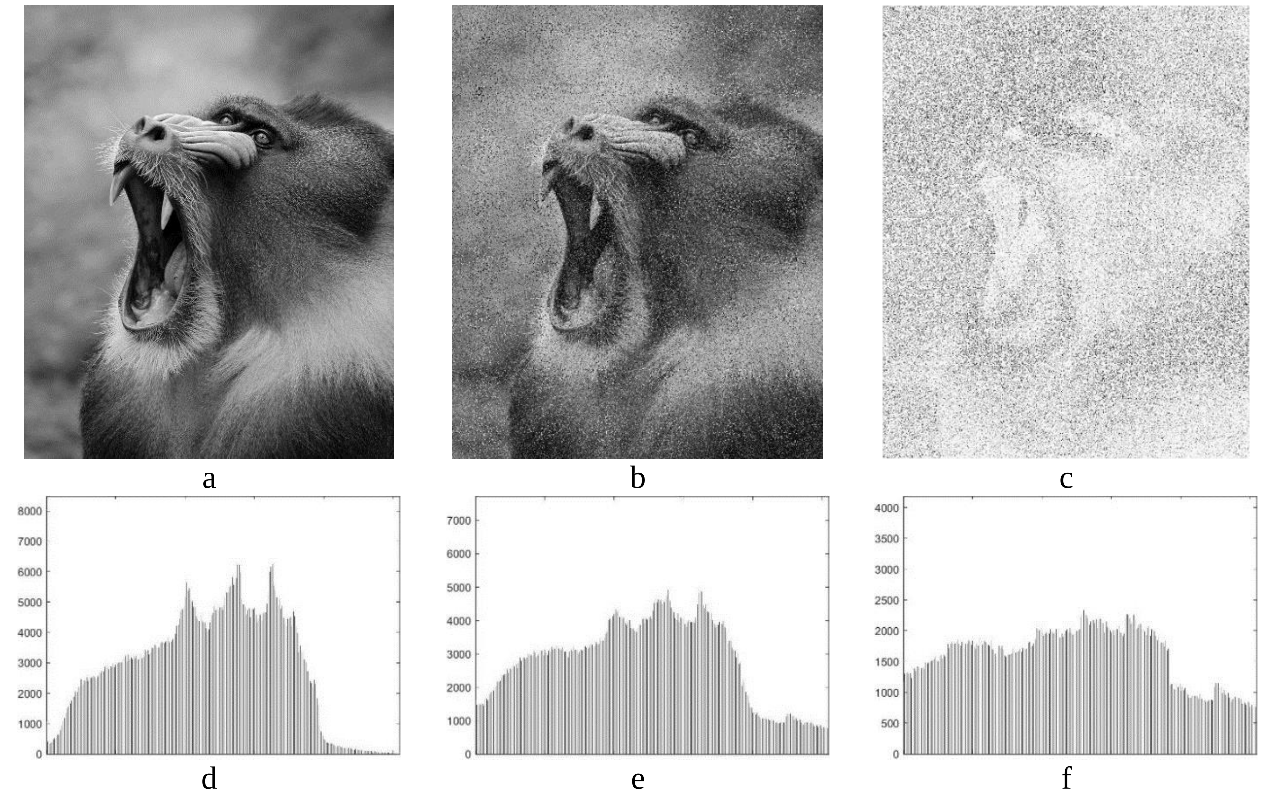


Figure 3. An example of image distortion transmitted via DSC:
a) the original undistorted image; b) image distorted by impulse noise; c) the location of impulse noise in the image; d) the distribution of pixel brightness in the undistorted image; e) distribution of pixel brightness in a distorted image; f) the distribution of the brightness of impulse noise in the image.

Figure 3 shows the distribution of pixels in an uncoded image transmitted via DSC. The figure shows that the distribution of distorted pixels and their brightness is close to uniform. Random in value and location in the image noise that is uniformly distributed corresponds to the characteristics of random -valued impulse noise. If the least significant digits of a bit are damaged, the distorted pixels take on values close to the original ones. Therefore, *in* Figure 3c , where only distorted noise values are presented, the silhouette of the original image is visible. To eliminate this type of noise impact, cleaning methods based on median filtering are suitable.

Method for detecting and cleaning random -valued impulse noise / Method for detection and cleaning random - valued impulse noise

Let digital images be represented by a set of pixels with intensity values $x_{i,j}$ whose coordinates (i, j) vary over some subset Z^2, where Z is the set of integers.

In the proposed method, on a noisy image, it is necessary to determine whether a pixel bit has been distorted. To do this, we introduce an estimate of the difference between pixels in the local window. The score is based on two parameters:

1) Parameter difference brightness pixels , which we offer count on formula
2)

$$V(i,j) = 1 + \{\log_2 \left| x_{i,j} - x_{a,b} \right| - 8, -8\}, \; x_{a,b} \in \Omega_{x_{i,j}} . \quad (4)$$

Next, sort U and sum the first $m/2$ elements, where m is the number of elements in the local window Ω:

$$A_m(x_{i,j}) = \sum_{l=1}^{m} V_l(x_{i,j}) . \quad (5)$$

3) Parameter geometric distance based _ on the Euclidean metric , which defines difference between pixels in local window Ω

$$B(x_{i,j}, x_{a,b}) = \exp\left(-\left\|x_{i,j} - x_{a,b}\right\|^2 / (2\alpha_B^2)\right), \tag{6}$$

where *(i , j)* and *(a , b)* denote pixel coordinates. The parameter α controls $B(x_{i,j}, x_{a,b})$ relative to the geometric distance.

As a result, the similarity parameters between two pixels are obtained, based on the geometric distance and the difference in brightness of the pixels in the detector window, with which you can get an estimate of the difference between the pixels C:

$$C(x_{i,j}, x_{a,b}) = A(x_{i,j}, x_{a,b}) \cdot B(x_{i,j}, x_{a,b}) . \tag{7}$$

The similarity score under formula (7) forms an array of values, where, using a certain threshold T , it is possible to determine whether a pixel is an impulse. In the proposed method, the optimal threshold value for $T = 20$. Therefore, if the C value in the array is greater than the threshold value, then the image pixel is an impulse.

We propose to use the filter mask of the following form, which is shown in Figure 4. The distance between pixels in the local window is proposed to be determined by the Euclidean metric (L_2) [8]. The distance $R\left(x_{ij}, x_{ab}\right)$ between pixels x_{ij} and x_{ab} in the metric L_2 is determined by the formula

$$R\left(x_{ij}, x_{ab}\right) = \sqrt{\left(i-a\right)^2 + \left(j-b\right)^2} .$$

2	1	2
1		1
2	1	2

Figure 4. Local window Ω . The squares of distances defined by the Euclidean metric are inscribed in the pixel cells L_2 .

For pixels defined as distorted in the local area Ω, an array of undistorted pixels is formed, in which the median is calculated. The resulting median value is assigned to the distorted pixel.

Results

For modeling, an 8-bit grayscale image was used, which is shown in Figure 2. Image resolution is 944 by 768 pixels. In the image, each bit c is distorted with probabilities $p = 0.01, 0.05, 0.1$. The peak signal-to-noise ratio (PSNR) [9] and structural similarity index (SSIM) [10] were used to determine the quality of image processing. The results of the experiment are presented in tables 1 and 2. In fig. 5-7 for clarity of the quality of processing, the original, distorted and restored images are shown.

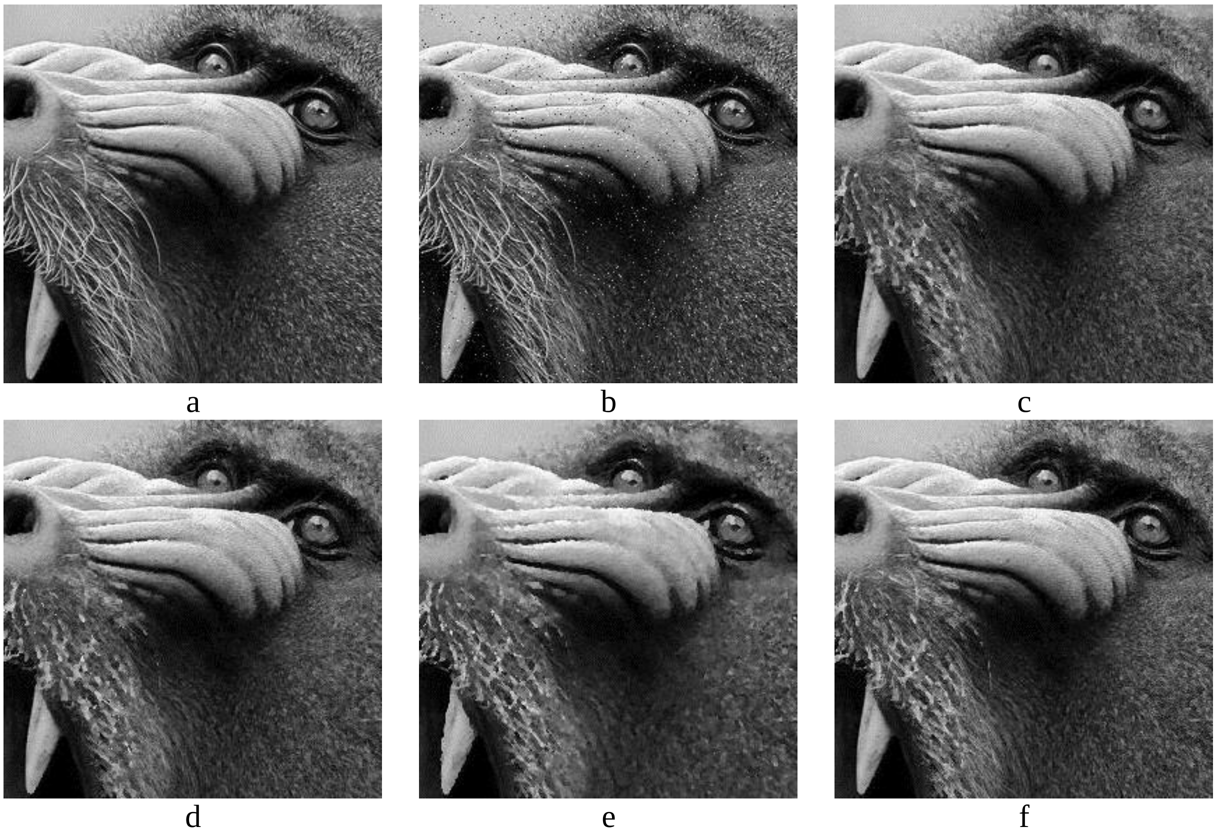


Figure 5. a) Fragment of the original image; b) a fragment of the image transmitted via DSC (p=0.01); c) the result of restoration by the method [5]; d) the result of restoration by the method [6]; e) the result of restoration by the method [7]; f) the result of recovery by the proposed method;

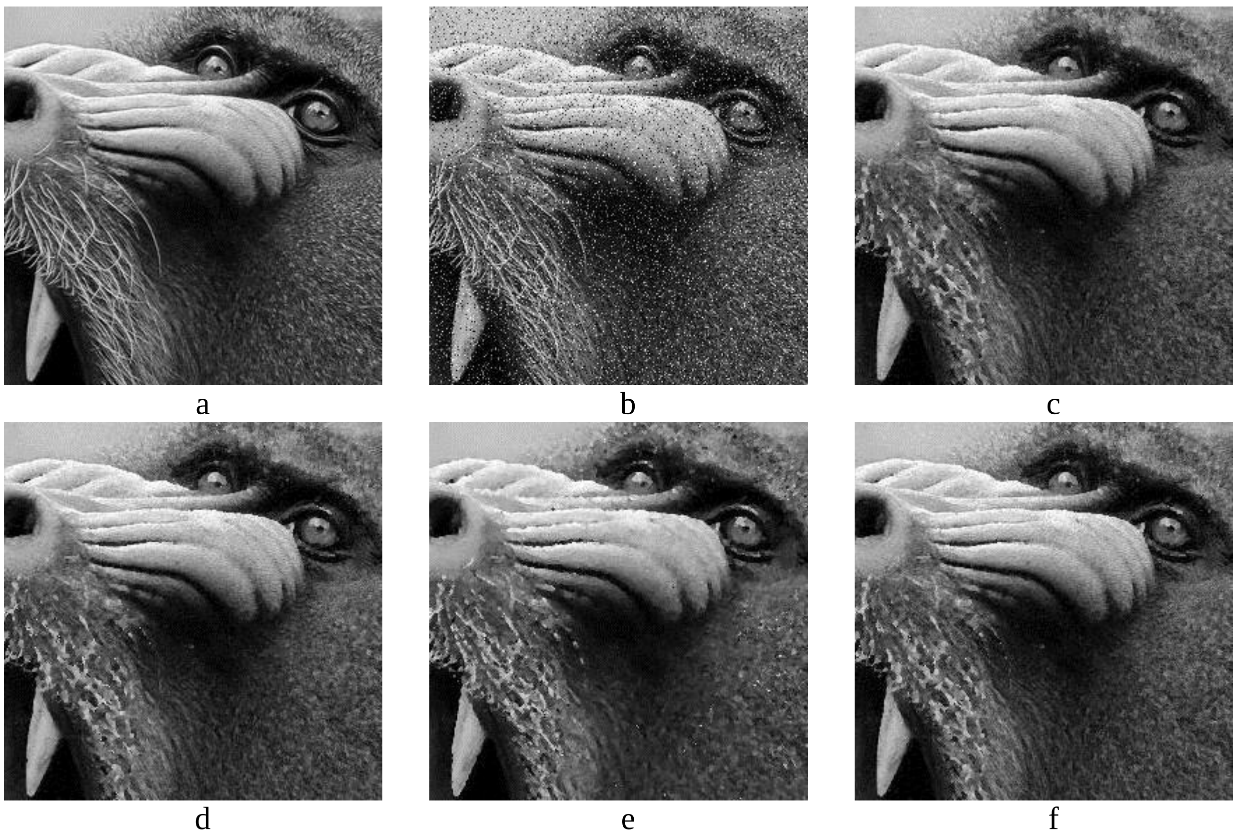


Figure 6. Fragment of the original image; b) a fragment of the image transmitted via DSC (p=0.05); c) the result of restoration by the method [5]; d) the result of restoration by the method [6]; e) the result of restoration by the method [7]; f) the result of recovery by the proposed method;

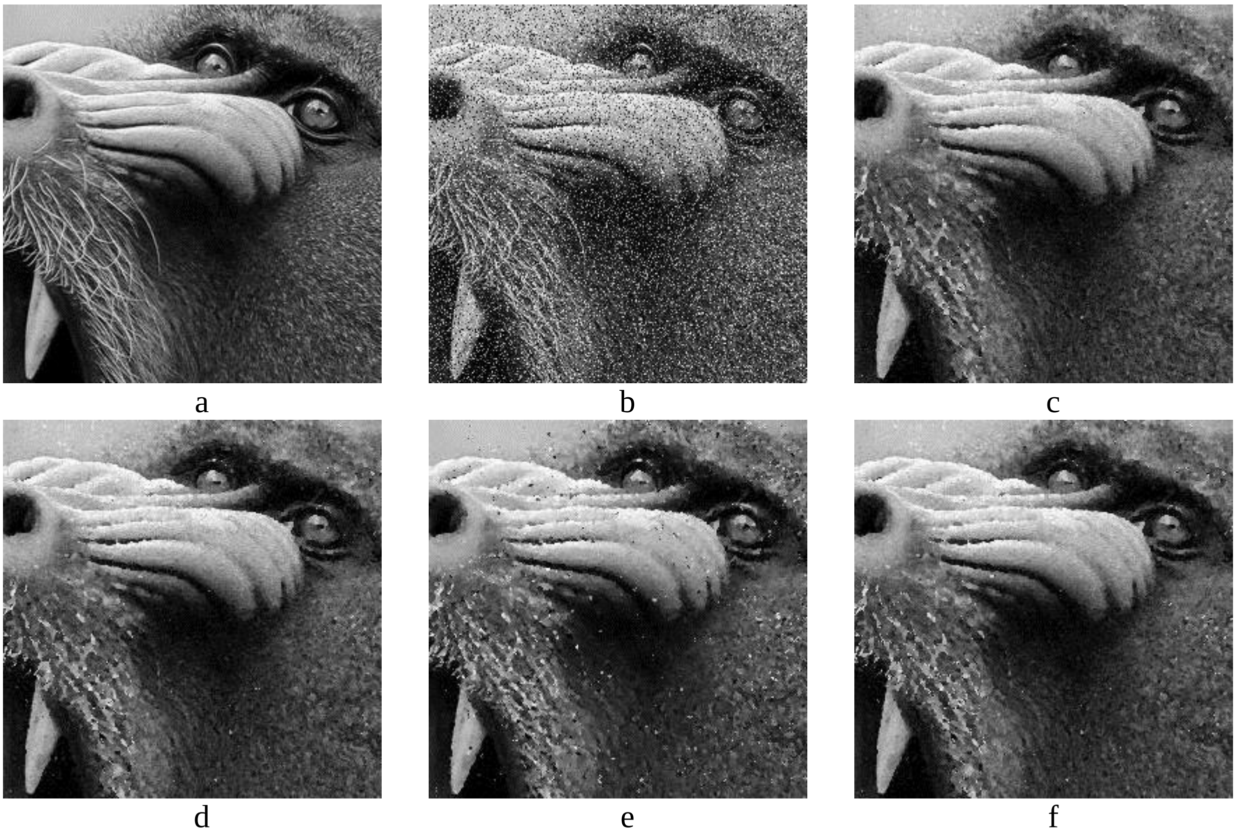


Figure 7. Fragment of the original image; b) a fragment of the image transmitted via DSC (p=0.1);
c) the result of restoration by the method [5]; d) the result of restoration by the method [6]; e) the result of restoration by the method [7]; f) the result of recovery by the proposed method;

Tab. Fig . 2. PSNR values for various methods of image cleaning from impulse noise.

Bit corruption probability, *p*	Known Methods			Suggested method
	[5]	[6]	[7]	
0,01	27, 254	26,866	25,661	**28,06 3**
0,05	25,723	25,601	25,200	**25,770**
0,10	24,146	**24,152**	23,244	24,138

Tab. Fig. 3. SSIM values for various methods of cleaning images from impulse noise.

Bit corruption probability, *p*	Known Methods			Suggested Method
	[5]	[6]	[7]	
0,01	0,901	0,891	0,795	**0,916**
0,05	0,762	0,776	**0,781**	0,775
0,10	0,609	0,637	**0,671**	0,646

The simulation showed the effectiveness of the proposed method. In tables 2-3, the best results among the considered methods are highlighted in bold. For the probability of bit distortion $p = 0,01$, the superiority of the proposed method can be traced. For the bit distortion probability, $p = 0,05$the proposed method is inferior in performance to SSIM . For the probability of bit distortion $p = 0,1$, the proposed method takes values close to the best.

Conclusion

The paper considers the transmission of images through a binary symmetric communication channel, where, with a certain probability, each bit of the image was distorted. The distribution of distortions in the image showed that the noise, random in value and location in the image, which is uniformly distributed, corresponds to the characteristics of random -valued impulse noise. A method was proposed for detecting and cleaning distorted pixels in images, which is based on estimating the difference between pixels in terms of brightness and geometric distance of pixels in the local window. The distances in the local window are defined by the Euclidean metric.

In the simulation, using the SSIM and PSNR characteristics, it was shown that the proposed method effectively coped with the task of denoising. The proposed method can be used, for example, in video surveillance systems, in data transmission using digital television technology in data networks using the IP protocol. And also in communication channels where weather conditions distort signals.

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