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THE USE OF Q-PREPARATION FOR AMPLITUDE FILTERING OF DISCRETED IMAGE

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Abstract. *The article was aimed at improving the amplitude filtering process of the sampled image through the use of generalized Q-preparation. The existing correlation algorithms for image preprocessing were analyzed and their advantages and disadvantages were identified. The process of amplitude filtering and the main methods of preprocessing with such filtering were considered. A method of amplitude filtering of images based on the generalized Q-transformation with the use of sum-difference preprocessing of images has been developed. The efficiency of this method was analyzed, and a variant of the scheme for the corresponding preprocessing of images was proposed. The efficiency of the method was confirmed by computer simulation.*

Keywords: amplitude filtering, generalized Q-preparation, correlation algorithms

ZASTOSOWANIE Q-PREPARACJI DO FILTROWANIA AMPLITUDOWEGO ZDYSKRETYZOWANEGO OBRAZU

Streszczenie. *Artykuł miał na celu usprawnienie procesu filtrowania amplitudy zdyskretyzowanego obrazu za pomocą uogólnionej Q-preparacji. Przeanalizowano istniejące algorytmy korelacji do wstępnego przetwarzania obrazu i określono ich wady i zalety. Omówiono proces filtracji amplitudowej oraz główne metody wstępnego przetwarzania z taką filtracją. Opracowano metodę filtrowania amplitudowego obrazów w oparciu o uogólnioną transformację Q z wykorzystaniem wstępnego przetwarzania obrazów na podstawie różnic sumy. Przeanalizowano skuteczność tej metody i zaproponowano wariant odpowiedniego schematu wstępnego przetwarzania obrazu. Skuteczność metody została potwierdzona symulacją komputerową.*

Słowa kluczowe: filtrowanie amplitudy, uogólniona Q-preparacja, algorytmy korelacji

Introduction

Pattern recognition is a relevant and promising area of information technologies, the scope of its application is expanding every year. In turn, recognition has separate tasks that must be solved in order to obtain the most accurate result. This includes the recognition [2, 11, 13] process itself, image preprocessing for detecting and eliminating interference, dividing image into segments, real-time recognition, etc. One of the urgent tasks in the field of pattern recognition is the task of creating correlation systems for automatic measurement of coordinates [5, 6]. In such systems, the functional of linking the current image and the reference image is calculated, as well as the coordinates of the extremum of this functional are determined. Among the advantages of such systems is the fact that they provide the ability to work in conditions of great uncertainty in the noise-signaling environment and provide resistance to the influence of decorrelating factors. Such factors can be: noise, uneven sensitivity, geometric distortions of the video sensor, errors in analog-to-digital conversion, etc [1, 7, 9].

Thus, the development and improvement of such systems makes it possible to recognize signals or images more accurately due to filtering under the influence of various environmental noises. The existing methods have their drawbacks, which can be eliminated using the method presented in the article, namely, using amplitude filtering using Q-preparation [3, 6, 8].

1. Analysis of literature data and problem statement

Modern image recognition systems are characterized by work in a difficult jamming environment. When designing such systems, can often encounter the problem of detecting signals in noise when their characteristics are not known in advance or are subject to changes. Signals in such systems are functions of two spatial coordinates and time and are called images. Correlation algorithms are very often used in such problems; the physical meaning of correlation processing in this case consists in combining images.

There are many correlation algorithms [1, 10, 17], the main ones are:

- optimal spatial filtration,
- background correlation,
- binary correlation,
- correlation of conversion factors,
- optical matched filter,
- three-dimensional correlation,
- combination of relative information vectors,
- combination of structural models.

With optimal spatial filtering, images are filtered to optimize registration. Optimal filters are constructed using typical images. The advantages of this method are the increased ratio of the main peak of the correlation function to the side lobes, the homogeneity of the side lobes, and the possibility of an analytical description. At the same time, the disadvantages of this method are that it is based on the knowledge of the gray level of the image, and the design of the filter requires the estimation of noise statistics [15].

Background correlation is a real correlation using the inverse Fourier transform of the mutual energy spectrum of the phase. The advantages of this correlation method are: sharp correlation peaks, implementation efficiency, and lack of sensitivity to narrowband noise. However, the method requires prediction of the gray level of the images and requires a broadband image plot [4, 16, 19].

For binary correlation, images are preliminarily converted into binary form. The method provides an efficient implementation and desensitization to errors in gray level prediction. In this case, the information content of the images decreases due to the transition to binary images, and there is a need to implement the prediction of the gray level of images.

The correlation of transform coefficients provides processing using the algorithm of the minimum absolute difference of the Hadamard coefficients of the reference and current images. Due to this, an increase in the sharpness of the peak and a decrease in sensitivity to noise are achieved. In this case, the method requires prediction of the gray level and gives an increase in the amount of computation [18].

An Optical Matched Filter is an analog matched filter using coherent light processing. The method provides almost instantaneous correction, has an extremely large amount of memory, and implements parallel processing of several reference images. The disadvantages are that it is based on gray level prediction, with the processing flexibility being limited by the hardware implementation [7, 20, 21].

Three-dimensional correlation combines a three-dimensional target model and active rangefinder data. No gray prediction is required here. The method can take into account all possible approaches to the approach and is insensitive to deliberate changes in target attributes. However, it requires a range sensor and a significant amount of computation.

The alignment of relative information vectors is based on maximizing the number of corresponding information-relative vectors. No gray prediction is required here. The method includes three-dimensional objects and is insensitive to contrast inversion. The disadvantage is that you need to implement feature extraction, the method is sensitive to noise, and the analytical description is difficult [6, 14].

When structural models are combined, feature models (lines, segments, tops, spots) are combined. The method does not require prediction of gray levels, is insensitive to contrast inversion, and has minimal memory requirements. However, it is necessary to implement feature extraction, the method is sensitive to noise, and the analytical description of the characteristics is difficult.

The classical algorithm for correlation image processing is understood as the calculation of a cross-correlation function or a convolution-type integral with the subsequent search for the maximum of this function. The disadvantage of the classical algorithm is a large amount of computation, since the calculation of the cross-correlation function is performed for all possible relative shifts of the processed images [1, 23]. Moreover, if the dimensions of the image are equal to M×M, N×N, then the number of points for which the correlation function is calculated is$(N-M+1)^2$. This number is usually significant.

In the process of preprocessing a sampled image, the most important task is to filter the amplitude and geometric noise [1], which are the result of external and internal noise influences on the processes of formation, registration, transformation and transmission of sampled images.

Amplitude noise distorts the value of the samples in the image of an object, while geometric noise changes the number and location of the samples associated with this image, i.e. samples exceeding, for example, the general signal detection threshold [1]. For each of these types of noise, there are separate methods for preprocessing (filtering) images.

In a number of applied problems of the theory of pattern recognition, preprocessing methods are used based on the formation of a difference image with its subsequent threshold preprocessing: delta modulation [1, 13], generalized contour preparation, contouring [7, 12], etc. All of them lead to an increase in the noise level of the transformed Images.

There are also heuristic preprocessing methods, their essence lies in the summation of local groups of samples of the converted image. But there are problems with their implementation. The first is to combine the operations of nonlinear difference of image preprocessing and averaging of local groups of samples to reduce image noise. The second problem is the creation of a processor element with a universal structure for a homogeneous processor environment, which will be suitable for performing sum-difference preprocessing operations. The last problem is related to determining the optimal sizes$P_{opt} \times q_{opt}$ a local group of image samples, averaged according to heuristic-type smoothing algorithms [8, 9], or a preprocessing algorithm using the partial Q-summation method.

Thus, the analysis shows that the existing methods of correlation are processing and image preprocessing have a number of disadvantages. This article proposes a method for amplitude filtering images to help avoid them [10, 22].

2. The purpose and objectives of the study

The article is focused on the development of a method for amplitude filtering of images. The proposed method uses a generalized Q-preparation, previously passed the sum-difference preprocessing of the type H_C, H_L or H_C, H_G ($\sum Q\Delta$-processing and $\sum Q\nabla$-processing, respectively).

To achieve this goal, it is necessary to consider the process of amplitude filtering of images, existing preprocessing methods for amplitude filtering, select one of them and develop an appropriate filtering method using generalized Q-preparation.

3. Materials and research methods

Amplitude filtering of a sampled image is a transformation of the amplitude of the central sample of a local group of samples according to the sample mean value of the amplitude of the sample of this group.

In accordance with this, the following preprocessing methods are used:

- averaging over the neighborhood of the elements,
- differential preprocessing in the neighborhood of elements,
- sum-difference preprocessing in the neighborhood of elements.

3.1. Averaging over the neighborhood of the elements

Spatial decorrelation of noise makes it possible to use efficient, easy-to-implement algorithms for averaging over the local neighborhood of elements based on the convolution of the original image $G(m,n)=\{g_{m,n}\}$, where $m=0,1,\dots,$ $M_1=\overline{0,\breve{E}_1}$ and $n=\overline{0,N_1}$ with array $H(a,c)=\{h_{a,c}\}$, where $|a|\le K_a>0, |c|\le c>0 \; and \; h_{a,c}>0$

$$\tilde{g}_{m,n}=\frac{1}{N_h}\sum_a\sum_c g_{m+a,n+c}h_{a,c} \tag{1}$$

where $N_h=\sum_a\sum_c h_{a,c}$ is the normalizing divider to exclude the shift of the mean value of the samples $\tilde{g}_{m,n}$ of the transformed image $\tilde{G}(m,n)=\{g_{m,n}\}$.

Most commonly used masks $H(a,c)$[17]

$$\frac{1}{9}\begin{bmatrix}1&1&1\\1&1&1\\1&1&1\end{bmatrix};\frac{1}{10}\begin{bmatrix}1&1&1\\1&2&1\\1&1&1\end{bmatrix};\frac{1}{16}\begin{bmatrix}1&2&1\\2&4&2\\1&2&1\end{bmatrix} \tag{2}$$

The use of these masks reduces the variance of the additive normal noise by $9 \div 7$, respectively, however, complicates the practical implementation of the filter due to the inclusion in (1) of samples diagonally located to the sample to be smoothed, and also due to the inconvenience of dividing by 9 for mask (2) when using traditional binary or binary-decimal system of coding image samples. In addition, these masks do not provide suppression of local noise spikes.

Therefore, the smoothing algorithm includes the following procedure

$$\tilde{g}_{m,n}=\begin{cases}g_{m,n}, |g_{m,n}-\bar{g}_{m,n}|\le\varepsilon\\ \bar{g}_{m,n}, |g_{m,n}-\bar{g}_{m,n}|>\varepsilon\end{cases} \tag{3}$$

where:

$\bar{g}_{m,n}=\frac{1}{8}\sum_a\sum_c g_{m+a,n+c}(a,c)\ne(0,0)$, $\varepsilon>0$ for example, ε does not exceed $\frac{1}{4}$ of the maximum possible value of $g_{m,n}$.

Given the above, it seems appropriate using simpler smoothing masks as follows kind:

$$\frac{1}{5}\begin{bmatrix}0&1&0\\1&1&1\\0&1&0\end{bmatrix};\frac{1}{4}\begin{bmatrix}0&1&0\\1&0&1\\0&1&0\end{bmatrix} \tag{4}$$

In this case, along with the limiting simplification of practical implementation, the deterioration of smoothing to ~ 2.25 times (estimated by variance) in comparison with the previously considered masks can be compensated for by subsequent processing.

3.2. Difference preprocessing based on the neighborhood of elements

Fig. 1 shows the masks corresponding to some currently widespread types of local difference image preprocessing by neighborhood 3×3 element. In this case, the differences in direction, the Laplacian and the gradient for the masks (Fig. 1) are respectively defined as follows:

$$\Delta^{(0,1)} g_{m,n} = \left|\left(g_{m-1,n+1} + g_{m,n+1} + g_{m+1,n+1}\right) - \right.$$
$$\left. - \left(g_{m-1,n-1} + g_{m,n-1} + g_{m+1,n-1}\right)\right| \quad (5)$$

$$\Delta^{(1,0)} g_{m,n} = \left|\left(g_{m-1,n+1} + g_{m-1,n} + g_{m-1,n-1}\right) - \right.$$
$$\left. - \left(g_{m+1,n+1} + g_{m+1,n} + g_{m+1,n-1}\right)\right| \quad (6)$$

$$\Delta g_{m,n} = \frac{1}{8}\left(-\sum_a \sum_c g_{m+a,n+c} + 8 g_{m,n}\right), (a,c) \neq (0,0) \quad (7)$$

$$\Delta g_{m,n} = \left(-\sum_a \sum_c g_{m+a,n+c} + 4 g_{m,n}\right), (a,c) \neq (0,0) \quad (8)$$

$$\nabla g_{m,n} = \left|g_{m,n} - g_{m+1,n}\right| + \left|g_{m,n} - g_{m,n+1}\right| \quad (9)$$

$$\underset{a)}{\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}} \quad \underset{b)}{\begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}} \quad \underset{c)}{\begin{bmatrix} 1 & -2 & 1 \\ -2 & 5 & -2 \\ 1 & -2 & 1 \end{bmatrix}}$$

$$\underset{d)}{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix}} \quad \underset{e)}{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & -1 & 0 \end{bmatrix}} \quad \underset{f)}{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix}} \quad \underset{g)}{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 0 \end{bmatrix}}$$

$$\underset{h)}{\begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}} \quad \underset{i)}{\begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}} \quad \underset{j)}{\frac{1}{8}\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}}$$

$$\underset{k)}{\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}} \quad \underset{l)}{\begin{bmatrix} 0 & -1 & 0 \\ 0 & 2 & -1 \\ 0 & 0 & 0 \end{bmatrix}} \quad \underset{m)}{\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}}$$

Fig. 1. Local differential processing masks

Note that the quasi-Laplacian masks used here and below (Fig. 1) differ from the corresponding masks (Fig. 1) of the mathematical definition of the Laplacian (11) by the presence of a factor $\frac{1}{N_h}$ (N_h equals 8 or 4) averaging the pairwise differences between the central sample and the samples corresponding to the coefficients –1 of the filter of the following masks:

$$\underset{H_{L8}}{\frac{1}{8}\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}}; \quad \underset{H_{L4P}}{\frac{1}{4}\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}}; \quad \underset{H_{L4D}}{\frac{1}{4}\begin{bmatrix} -1 & 0 & -1 \\ 0 & 4 & 0 \\ -1 & 0 & -1 \end{bmatrix}} \quad (10)$$

Calculation of the quasi-Laplacian according to the mask H_{L4P} is simpler than calculating it according to the masks H_{L8} and H_{L4D}. Masks H_{L8} and H_{L4P} insignificantly, no more than 1.25 times, increase the noise variance; therefore, their use is advisable for low-noise images. Similarly to the masks of the quasi-Placian, we introduce the masks of the quasi-gradient H_{G8}, H_{G4P} and H_{G4D}:

$$\underset{H_{G8}}{\frac{1}{4}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 0 & -1 \\ -1 & -1 & -1 \end{bmatrix}}; \quad \underset{H_{G4P}}{\frac{1}{2}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & 0 \end{bmatrix}}; \quad \underset{H_{G4D}}{\frac{1}{2}\begin{bmatrix} 1 & 0 & -1 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}} \quad (11)$$

Calculating the quasi-gradient according to the mask H_{G4P} is simpler than calculating it according to the masks H_{G8} and H_{G4D}.

3.3. Sum-difference preprocessing by the neighborhood of elements

For noisy images, before calculating the quasi-Placian or quasi-gradient, it is advisable to pre-smooth the noise with appropriate masks:

$$\underset{H_{C8}}{\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \end{bmatrix}}; \underset{H_{C4P}}{\frac{1}{4}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}}; \underset{H_{C4D}}{\frac{1}{4}\begin{bmatrix} 1 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 1 \end{bmatrix}} \quad (12)$$

Let us find a reduction in image noise by sequentially applying one of the smoothing masks (14) and one of the differential preprocessing masks (12) or (13). For this, consider the neighborhood 5× 5 elements *mn*-th image element, which corresponds to a set of readings $\{q_{m+a,n+c}\}$, $a = \overline{-2.2}$, $c = \overline{-2.2}$. As an example, consider the sequential application of masks H_{C8} and H_{L8}:

$$\tilde{q}_{m+a1,n+c1} = \sum_{a_2} \sum_{c_2} q_{m+a_1+a_2,n+c} \cdot h_{c_8,a_1+a_2,c_1+c_2},$$
$$a_2 = \overline{-1.1}, c_2 = \overline{-1.1} \quad (13)$$

The equivalent calculation mask according to (15) is shown in Fig. 2.

Equivalent computation masks for other possible combinations of smoothing masks and differential preprocessing masks are shown in Fig. 2 and Fig. 3, and the corresponding coefficients for reducing the noise variance in table 1 and 2.

To simplify the analysis, Fig. 2, 3 empty spaces are left in place of mask coefficients with zero values.

$$\underset{a)\ (H_{C8}, H_{L8})}{\frac{1}{64}\begin{bmatrix} -1 & -2 & -3 & -2 & -1 \\ -2 & 6 & 4 & 6 & -2 \\ -3 & 4 & -6 & 4 & -3 \\ -2 & 6 & 4 & 6 & -2 \\ -1 & -2 & -3 & -2 & -1 \end{bmatrix}} \quad \underset{b)\ (H_{C8}, H_{L4P})}{\frac{1}{32}\begin{bmatrix} & -1 & -1 & -1 & \\ -1 & 2 & 2 & 2 & -1 \\ -1 & 2 & -4 & 2 & -1 \\ -1 & 2 & 2 & 2 & -1 \\ & -1 & -1 & -1 & \end{bmatrix}} \quad \underset{c)\ (H_{C8}, H_{L4D})}{\frac{1}{32}\begin{bmatrix} -1 & -1 & -2 & -1 & -1 \\ -1 & 4 & 2 & 4 & -1 \\ -2 & 2 & -4 & 2 & -2 \\ -1 & 4 & 2 & 4 & -1 \\ -1 & -1 & -2 & -1 & -1 \end{bmatrix}}$$

$$\underset{d)\ (H_{C4P}, H_{28})}{\frac{1}{32}\begin{bmatrix} & -1 & -1 & -1 & \\ -1 & 2 & 6 & 2 & -1 \\ -1 & 6 & -4 & 6 & -1 \\ -1 & 2 & 6 & 2 & -1 \\ & -1 & -1 & -1 & \end{bmatrix}} \quad \underset{e)\ (H_{C4P}, H_{L4P})}{\frac{1}{16}\begin{bmatrix} & & -1 & & \\ & -2 & 4 & -2 & \\ -1 & 4 & -4 & 4 & -1 \\ & -2 & 4 & -2 & \\ & & -1 & & \end{bmatrix}} \quad \underset{f)\ (H_{C4P}, H_{L4D})}{\frac{1}{16}\begin{bmatrix} & -1 & & -1 & \\ -1 & 4 & 2 & 4 & -1 \\ & 2 & & 2 & \\ -1 & 4 & 2 & 4 & -1 \\ & -1 & & -1 & \end{bmatrix}}$$

$$\underset{g)\ (H_{C4D}, H_{L8})}{\frac{1}{32}\begin{bmatrix} -1 & -1 & -2 & -1 & -1 \\ -1 & 8 & -2 & 8 & -1 \\ -2 & -2 & -4 & -2 & -2 \\ -1 & 8 & -2 & 8 & -1 \\ -1 & -1 & -2 & -1 & -1 \end{bmatrix}} \quad \underset{h)\ (H_{C4D}, H_{L4P})}{\frac{1}{16}\begin{bmatrix} & -1 & & -1 & \\ -1 & & 2 & & -1 \\ & 2 & & 2 & \\ -1 & & 2 & & -1 \\ & -1 & & -1 & \end{bmatrix}} \quad \underset{i)\ (H_{C4D}, H_{L4D})}{\frac{1}{16}\begin{bmatrix} -1 & & -2 & & -1 \\ & 4 & & 4 & \\ -2 & & -4 & & -2 \\ & 4 & & 4 & \\ -1 & & -2 & & -1 \end{bmatrix}}$$

Fig. 2. Equivalent computation masks for possible combinations of smoothing masks and masks of differential preprocessing

Table 1. Combinations of masks and dispersion reduction factors

Combination of masks	H_{C8} H_{L8}	H_{C8} H_{L4P}	H_{C8} H_{L8D}	H_{C4P} H_{L8}	H_{C4P} H_{L4P}	H_{C4P} H_{L4D}	H_{C4D} H_{L8}	H_{C4D} H_{L4P}	H_{C4D} H_{L4D}
Dispersion reduction coefficient	11.91	11.07	8.26	5.45	2.56	2.91	8.26	10.67	2.56

$$\frac{1}{32}\begin{bmatrix}1&2&3&2&1\\2&2&2&&2\\3&&&&3\\2&&-2&-2&2\\1&2&3&2&1\end{bmatrix}\quad \frac{1}{16}\begin{bmatrix}&-1&1&1&\\1&2&&&-1\\1&&&&-1\\1&&&-2&-1\\&-1&-1&-1&\end{bmatrix}\quad \frac{1}{16}\begin{bmatrix}1&1&&-1&-1\\1&&&&-1\\2&2&&2&-2\\1&&&&-1\\1&1&&-1&-1\end{bmatrix}$$

$a)\ (H_{C8}, H_{G8})$ $b)\ (H_{C8}, H_{G4P})$ $c)\ (H_{C8}, H_{G4D})$

$$\frac{1}{32}\begin{bmatrix}&1&1&1&\\1&2&2&&1\\1&&&&-1\\-1&&-2&-2&-1\\&-1&-1&-1&\end{bmatrix}\quad \frac{1}{8}\begin{bmatrix}&&1&&\\&2&&&\\1&&&&-1\\&&&-2&\\&&-1&&\end{bmatrix}\quad \frac{1}{8}\begin{bmatrix}&1&&-1&\\1&2&&&-1\\&&&-2&\\1&&&&-1\\&1&&-1&\end{bmatrix}$$

$d)\ (H_{C4P}, H_{G8})$ $e)\ (H_{C4P}, H_{G4P})$ $f)\ (H_{C4P}, H_{G4D})$

$$\frac{1}{16}\begin{bmatrix}1&1&2&1&1\\1&&&&-1\\&&&&\\1&&&&-1\\-1&-1&-2&-1&-1\end{bmatrix}\quad \frac{1}{8}\begin{bmatrix}&1&&1&\\1&&&&-1\\&&&&\\1&&&&-1\\&-1&&-1&\end{bmatrix}\quad \frac{1}{8}\begin{bmatrix}1&&&&-1\\&&&&\\2&&&&-2\\&&&&\\1&&&&-1\end{bmatrix}$$

$g)\ (H_{C4D}, H_{G8})$ $h)\ (H_{C4D}, H_{G4P})$ $i)\ (H_{C4D}, H_{G4D})$

Fig. 3. Equivalent computation masks for possible combinations of smoothing masks and masks of differential preprocessing

Table 2. Combinations of masks and dispersion reduction factors

Combination of masks	H_{C8} H_{G8}	H_{C8} H_{G4P}	H_{C8} H_{G8D}	H_{C4P} H_{G8}	H_{C4P} H_{G4P}	H_{C4P} H_{G4D}	H_{C4D} H_{G8}	H_{C4D} H_{G4P}	H_{C4D} H_{G4D}
Dispersion reduction coefficient	11.64	12.8	9.14	9.14	5.33	4	12.8	8	5.33

From a comparison of the data table. 1 and 2, it follows that the combination of masks of local averaging and quasi-gradient gives, on average, a significantly greater noise reduction than the combination of masks of local averaging and quasi-gradient. It is important that the minimum value of the coefficient of variance reduction for table 2 is ≈1.6 times higher than its value for table 1 and not less than the value of this coefficient for a separate smoothing mask (8 – for H_{C8}, 4 - for H_{C4P} or H_{C4D}).

From the point of view of performing the total-difference processing of each type, according to table. 1 or 2, in a processor element with a universal structure, combinations of masks (H_{C8}, H_{L8}), (H_{C4P}, H_{G4P}), and (H_{C4D}, H_{G4D}) are attractive, while preprocessing for the last two combinations of masks is simpler in practical implementation.

3.4. Amplitude filtering of images using generalized Q-preparation

Of course, each of the images $G_l(m, n)$ be subjected to a generalized Q-preparation by the method of generalized Q-preparation (GQP) or partial Q-summation (PQS) [6], i.e. it does not take into account that this image was obtained as a result of sum-difference preprocessing.

However, taking into account the total-difference preprocessing when carrying out a generalized Q-transformation of an image, in particular, GQP, does not allow obtaining significant hardware savings without reducing the efficiency of subsequent processing of the prepared image, for example, when it is correlated-extreme comparison with the prepared reference image. In this case, taking into account the total-difference character of the GQP image converted by the method $G_l(m, n)$ Z ∈ *{l,g}* and using the concept of local difference threshold (LDT) (drop detection threshold), generalized Q-preparation is mathematically described as follows (Tab. 3):

$$\hat{g}_{zm,n} = \begin{cases} a^{+}, when\ g_{zm1n} \geq q \\ a^{0}, when\ \left|g_{Zm,n}\right| < q \\ a^{-}, when\ g_{zm1n} \leq -q \end{cases} \tag{14}$$

where Z ∈ {l, g}, $\hat{g}_{zm,n}$ is the readout of the generalized Q-preparation (GQP) $\hat{G}_{z(m,n)} = \{g_{zm,n}\}$ of the original image $\hat{G}_z(m_1 n)$.

The most compact is GQP, obtained as a result of rank signed delta modulation [11], for which the following takes place:

$$a^{+} = a,\ a^{0} = 0,\ a^{-} = -a \tag{15}$$

In this case, according to (19), signals with positive, zero and negative potential values, respectively, should correspond to the numbers a^{+}, a^{0} and a^{-} in the medium for storing the GQP.

3.5. Research results

Let us consider the features of the representation of the elementary sections of the brightness surfaces by the GQP of the quasilaplacian and the quasi-gradient (Q_Δ and Q_∇, respectively), and it seems expedient to take areas of flat, cylindrical and spherical surfaces as reference surfaces. In this case, a flat surface is characterized by the constancy of derivatives along any two mutually orthogonal directions, a cylindrical surface is characterized by the constancy of an arbitrary one along one of two mutually orthogonal directions (which coincides with the direction of the generatrix of this surface), and a spherical surface is characterized by the variability of the derivative along any two mutually orthogonal directions.

Table 3.Values 00 of Q_∇ and Q_Δ of reference surfaces

Surface type / Countdown GQP	Sphere		Plane	Cylindrical	
	convex	concave		convex	concave
Q_∇	+, 0, - +	+, 0, - -	+, 0, - 0	+, 0, - +	+, 0, - -
Q_Δ	+	-	0	+	-

The division factor for the intensity of the fiber-optic switch 2 is 2. A variant of the circuit in Fig. 4 b is more preferable in terms of hardware costs and less complexity of connections between OPS.

These results were obtained from computer simulations of the obtained method of amplitude image filtering using generalized Q-preparation on the developed scheme (Fig. 4). The system was designed and the corresponding program was written in the C++ programming language. The program simulates the operation of the obtained method, using the sum-difference preprocessing in the vicinity of the elements. Various local difference thresholds were also used to check performance of the method. A set of reference images and images from the test sample were used. Obtained earlier results were confirmed by simulation.

To check the effectiveness of the method, the reference and test images used in the simulation were processed by the main filtering methods discussed at the beginning of the paper. In comparison with the developed method, they provide less processing efficiency, namely, a larger amount of calculations, require more processing time, and have less system flexibility.

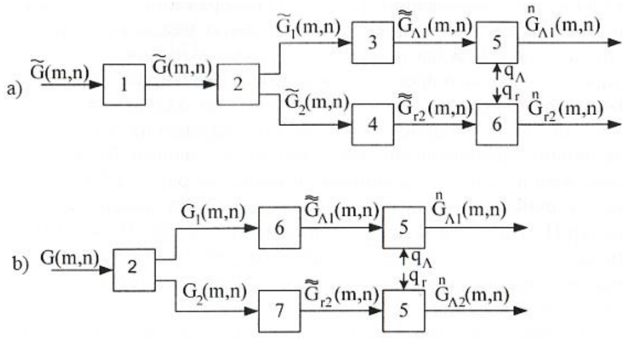

Fig. 4. Option of two-channel image preprocessing: 1, 3–7 – homogeneous processing environments for averaging, calculating Q_Δ and Q_∇ OQP, respectively; 2 – fiber optic switch

The use of other preprocessing methods for generalized Q-preparation of images was discussed above and confirms that the most effective for that purpose will be the sum-difference preprocessing using the local difference threshold.

The figure 5 shows an example of comparing two biomedical images over time using the proposed method.

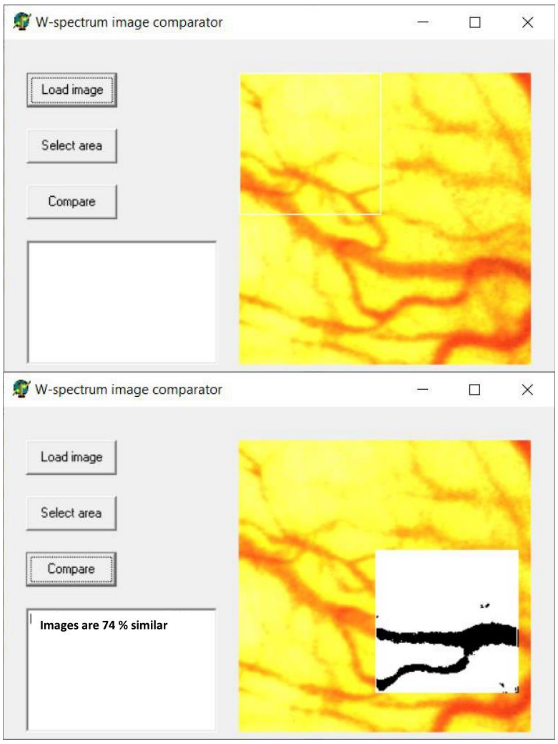

Fig. 5. Comparing two biomedical images over time

3.6. Discussion of the results

The convenience of entering the characteristics Q_Δ and Q_∇ is explained by the properties of their local isotropy, that is, regardless of the direction when processing in a 3×3 window. Therefore, with GQP Q_Δ and Q_∇ in the learning process, there are no stages of optimization in terms of the magnitude and direction of the rank vector [1], which achieves a significant saving in time and hardware costs. At the same time, the adaptive properties of preprocessing to the information problem being solved remain high, both due to varying the value of LRS q, and due to the possibility of using the methods of generalized Q-transformation at the following levels of representation Q_Δ and Q_∇ the processed luminance image.

4. Conclusions

The article considered the recognition of sampled images in conditions of noise in the image. The analysis of the corresponding correlation preprocessing algorithms was carried out and their advantages and disadvantages were presented. Methods for filtering amplitude noise were considered and, accordingly, the goal and objectives of the study were set. The methods of preprocessing with amplitude filtering were considered. On their basis, using a generalized Q-preparation, an amplitude filtering method with a sum-difference image preprocessing was developed. Also was suggested the scheme of two-channel image preprocessing based on the developed method and was carried out computer simulation, which confirmed good performance and effectiveness of the method. The resulting method has a number of advantages. It provides significant savings in time and hardware costs due to the lack of optimization stages in terms of the magnitude and direction of the rank vector. Also, the high adaptive properties of preprocessing to the information problem being solved are preserved. Thus, the obtained method can be used for preprocessing discretized images when carrying out their amplitude filtering, while increasing the recognition efficiency.

The implementation of the Q-preparation principle is described in [15, 16, 19].

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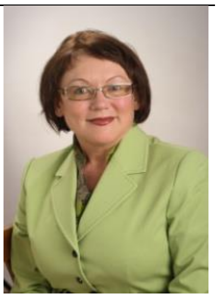

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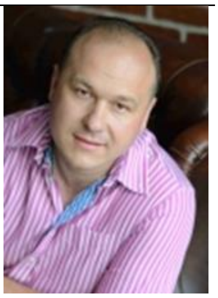

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