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Filtering methods in speckle noise reduction in biomedical images

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ABSTRACT

A review of the methods of filtering ultrasound images on the example of hip dysplasia images is presented, their advantages and disadvantages are shown. Demonstrated ways of computer diagnostics of Hip dysplasia development. The method of filtration of the speckle noise of ultrasonic images of the hip dysplasia was proposed. The proposed method focuses on Gaussian blur effects. The idea of the method is that performs a logical AND operation between the original input image and two another images processed Gaussian filtering. The algorithm was tested on the tested images, as well as on real ultrasound images of hip dysplasia.

Keywords: ultrasonic images, speckle noise, image processing.

1. INTRODUCTION

Timely diagnosis and early treatment of pathologies in the early stages of their development always yields an effective result. The need for early diagnosis necessitates the development and improvement of medical diagnostic systems[1,2]. Ultrasound research in modern medicine is a fairly common method of diagnosis. Ultrasound of the human body provides diagnostics of local anomalies and developmental defects, degenerative-dystrophic diseases of the joint-articular apparatus, primary and secondary tumors, various pathologies of bones, chest organs, abdominal cavity, skull, etc. The problem is that ultrasound images are clogged with noise. Therefore, it is necessary to develop approaches to suppress noise.

There are two main approaches aimed at suppressing noise in ultrasound images: averaging over frames and post-processing. Each of these approaches has drawbacks:

- frame averaging reduces the actual frame rate, since the resulting image processing is a superposition of several processed frames. Therefore, the image of moving objects, when overlapping several frames, may be fuzzy, blurred[3,4],
- the result of the post-processing filter is a possible loss of detail, although the "readability" of the processed image is better than the original[5,6].

Therefore, the development of the method of suppressing speckle noise, which would eliminate the speckle noise in the image as much as possible, while maintaining small informative details, is still not a fully solved problem. The main idea of the methods of averaging over frames is to compare a series of ultrasound images of the same object in different directions of scanning and with different scanning frequencies or under different voltages and averaging the resulting images for the formation of the resulting. The original image contains less noise. In this way, the quality of the definition of objects can be improved, but at the same time part of the resolution is lost, the system becomes more complex and less efficient[6-9].

Postprocessing methods do not require significant hardware costs. They are based on the use of the principles of discrete mathematics for the obtained static ultrasound images. Postprocessing methods are divided into 2 large groups: single-scale and multi-scale. A common disadvantage of these methods is the partial loss of information due to the blurring of contour lines.

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In one-dimensional methods, the image is processed without changing its size, within the scope of the input scale. Univariate methods include averaged filters, media filters, specialized filters Li, Frost, Kuan, Wiener, Peroni-Malik, and filters based on the methods of increasing diffuse regions, described in papers[11].

In the work, ultrasound images of the child's hip joint were used. The purpose of the work is finding the method of post-treatment of ultrasound images for further computer diagnostics, and quantitative assessment of the development of child's dysplasia. For computer analysis of child dysplasia, the most appropriate methods are those that use the measurement of the geometry of the baseline and the elements of the hip joint. Computer analysis of 2D ultrasound images with appropriate computer processing will provide refined results for the diagnosis of hip dysplasia and its classification by Graf, as well as an accurate description of morphology of the ripening curve (development) of the spinal cavity[11,12] Fig. 1, Fig. 2.

2. ANALYSIS OF THE FILTERING METHODS OF THE SPECKLE NOISE OF ULTRASONIC IMAGES OF THE HIP DYSPLASIA

The average filter has the property of localizing the signal within a certain area, thus reducing the signal/noise ratio. It only requires the user to determine the size of the sliding window and specify the appropriate mask ratios[13,14]:

$$b(n_1,n_2)=\frac{1}{N\cdot M}\sum_{n_1,n_2\in N\cdot M}\omega(a,b)\cdot a(n_1,n_2) \tag{1}$$

N, M – the dimensions of the sliding window (masks); $\omega(a, b)$- the value of the coefficients of the mask; $a(n_1, n_2)$ – initial image; $b(n_1, n_2)$ – filtered image.

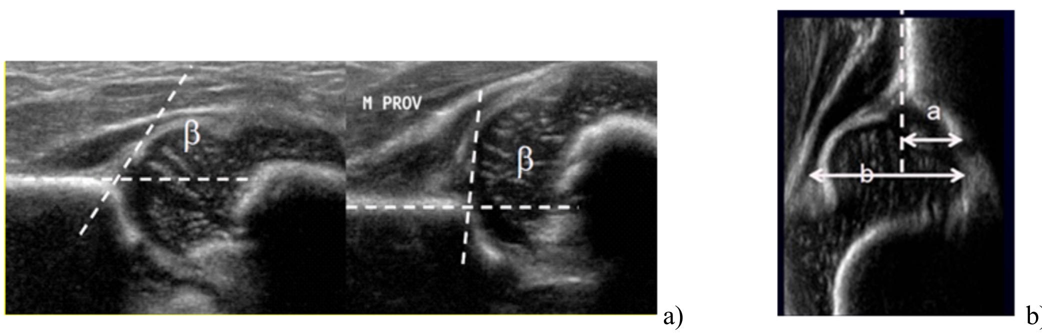


Figure 1. a) System of diagnosis and classification of hip dysplasia, based on subjective assessment of the bone triangle, as well as measurements of the angle between the Baseline and the Cartilage roof line (β angle); b) Diagnosis of hip dysplasia by the method of "Modified Morin – Terjecen". Bony rim percentage = Femoral head coverage (FHC) = $a/b \times 100$.

However, the undesirable effect of using such a filter is to blur the image. This filter is optimal for filtration of Gaussian additive noise, while the noise-emitting noise of the image corresponds to the model of multiplicative noise. The use of a simple averaging filter is not optimal for processing images of ultrasound diagnostics. The median filter is used to filter mainly pulsed noise and has become widespread due to its reliability and the ability to save the contour. The median filter uses the median pixel intensity value within the surroundings, thus creating less blurred images than the averaged filter[15],

$$b(n_1,n_2)=med\left(\sum_{n_1,n_2\in N\cdot M}a(n_1,n_2)\right) \tag{2}$$

The filter also requires setting the size of the slider window. The disadvantages of this filter are a partial loss of details, due to blurring of the image. Modeling for filtration of speckle noise of ultrasonic imaging of the hip joint was carried out in Matlab. The window sizes were 3×3, 5×5, 7×7 and 9×9. Increaseing the size of the window makes the output image smoother, and the colors become more even. In this case, it is necessary to choose the optimal size of the window, so as not to lose the basic information on the ultrasound image. Quantitatively, the quality of the filtration was not evaluated, since the ultrasound image of the hip joint was already clogged with noise. And to compare the quality of the filtering, you need to have a clean image. To quantify the filtration, it is necessary to synthesize the speckle noise model and apply it to the ultrasound image, and then calculate the correlation function of the image before and after filtration.

The initial image is multiplied by $(-1)\ x + y$, in accordance with the expression. This is done so that its Fourier transformation turns out to be centered, that is, the origin of the coordinate for the function image will be in the center of the frequency rectangle at the point (M/2; N/2);

$$\xi[f(x, y)(-1)\ x + y] = F(u - M/2, v - N/2). \tag{3}$$

- A direct discrete Fourier transform (DFT), $F(u, v)$ an image obtained after the previous step, is calculated;
- the function $F(u, v)$ is multiplied by some transition function of the filter $H(u, v)$;
- the reverse DFT is calculated from the result of step 3;
- the required percentage of the result of step 4 is allocated;
- the result of step 5 is multiplied by $(-1)\ x + y$.

The multiplier suppresses some "superfluous" conversion frequencies, while leaving the others almost unchanged. The question of finding the transfer function of the filter is key, since it determines which frequency will be filtered[16]. Assuming $f(x, y)$ denotes input image after the step 1, and $F(u, v)$ – its Fourier transform, then Fourier transform of the original image is given by:

$$G(u, v) = H(u, v) \cdot F(u, v) \tag{4}$$

The multiplication of the functions of two variables H and F is done by element. The filtered image is obtained by calculating the inverse Fourier transform from the Fourier image $F(u, v)$, calculating it by the formula:

$$Filtered\ image = \xi - 1[G(u, v)] \tag{5}$$

The obtained image is obtained by separating the actual part from the last result and multiplying it by (–1)x + y to compensate for the effect of multiplying the input image by the same magnitude. The simulation using Fourier Filtering to reduce the speckle noise of ultrasonic imaging of the hip joint was carried out in Matlab.

Consider the results of the Fourier filtering of ultrasound images using the ideal filter Fig. 4. The main parameter for correction of noise of a speck is the cutoff frequency parameter. First, the cutting frequency will be set at 20%. Looking at the image, we see that the noise in some parts of the background is smoother, but the contours of the objects become blurred, and there is a wave effect around the line and rectangle. This is called the Gibbs effect. If the cutting algorithm were lowered even more, we would get more smoothness, but we would also lose sharpness in the image and the Gibbs effect would be more significant. Therefore, it is necessary to choose the optimal indexes of the image in the frequency domain, that is, between the greatest decrease in speckle noise and less distortion of the Gibbs effect. Figure 4 shows ultrasound images where the cutoff frequency in the frequency domain is selected 20%, 30%, 40%, 50%.

$$\left|K(\omega)\right|^2 = \frac{1}{1 + \left(\dfrac{\omega}{\omega_{cp}}\right)^{2n}} \tag{6}$$

where n denotes the order of the Butterworth filter.

Unlike the ideal low-pass filter, the transmitter feature of the Butterworth low pass filter has no rupture, which sets the exact boundary between the frequencies that pass through and the cut-off frequencies. The advantages of low-frequency Butterworth filters include a much lesser manifestation of undesirable blur effects and the appearance of false circuits in comparison with ideal low-pass filters. As the order of the low-frequency Butterworth filter increases, the blurring effects increase. It is believed that the second-order Butterworth low-pass filter is optimal in terms of compromise between low-frequency filtering efficiency and an acceptable level of display of false circuits and overall image blurring.

The Butterworth filter tries to reduce speckle noise by cutting off the frequency and eliminating the Gibbs effect. Excessive detailing of the high-frequency image is reduced due to power loss and noise reduction. According to the results of the simulation, it can be said that with increasing the cut-off frequency range, speckle noise decreases and the Gibbs effect does not appear. The negative side of this filter is that the objects are a little blurred[17,18].

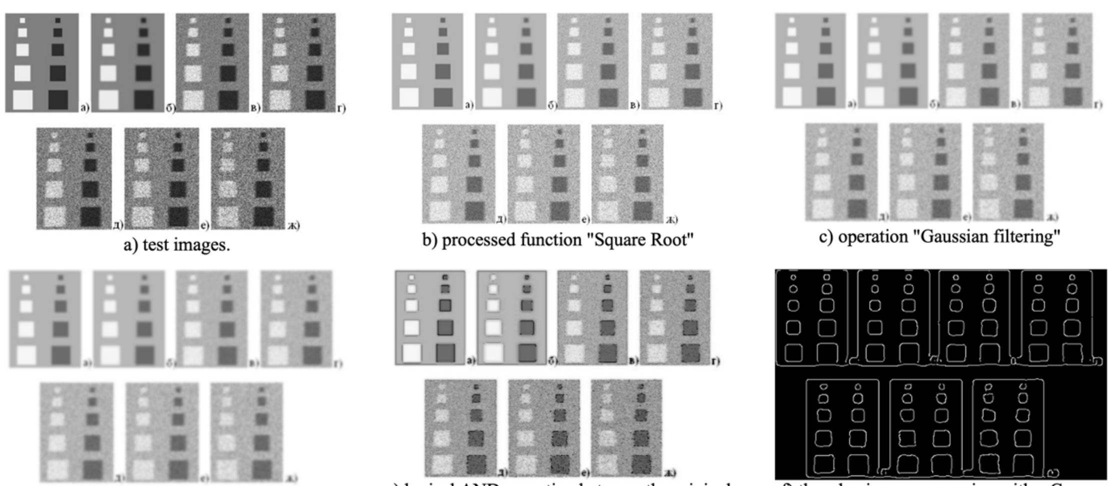
3. PROPOSED METHOD OF FILTRATION OF THE SPECKLE NOISE OF ULTRASONIC IMAGES OF THE HIP DYSPLASIA

Today it is very popular to use the tools of logical operations in image processing. Image arithmetic applies one of the standard arithmetic operations or a logical operator to two or more images. The operators are applied in a pixel-by-pixel way, i.e. the value of a pixel in the output image depends only on the values of the corresponding pixels in the input images. Hence, the images must be of the same size. Although image arithmetic is the most simple form of image processing, there is a wide range of applications. A main advantage of arithmetic operators is that the process is very simple and therefore fast. Logical operators are often used to combine two (mostly binary) images. In the case of integer images, the logical operator is normally applied in a bitwise way.

The NI Vision Assistant package was chosen as a tool to simulate speckle noise filtering. A comfortable and functional addition, greatly enhancing the user experience, is NI Vision Assistant. It enables to easily create own routines to capture, filter, process, analyze and edit the images, change settings of the cameras being used. These routines can be imported into Labview. Visualization and ease of use are the main advantage of such an approach, as the result of function application is visible at once.

Since the proposed method focuses on Gaussian blur effects, we use this blur method to build an algorithm and demonstrate the simulation results on test images. In image processing, the Gaussian distribution needs to be approximated by a convolution kernel. Therefore, values from this distribution are used to build a convolution matrix then applied to the original image. Each pixel's new value is a weighted average of that pixel's neighborhood. Thus, the original pixel's value receives the heaviest weight (having the highest Gaussian value) and neighboring pixels receive smaller weights as their distance to the original pixel increases. The convolution with the Gaussian kernel is a low-pass filter, that smoothes the borders of the image.

The input image Etalon Noise.jpg (32 bits) – 523×332 Fig. 3a) is converted to 8 bits "HSL" – Luminance Plane— Extracts the luminance plane from an HSL image. Hereinafter, operation "Lookup Table" improves contrast and brightness by applying a lookup table to an image. A lookup table (LUT) contains values used to transform the grayscale values of an image. For each grayscale value in the image, the corresponding new value is obtained from the LUT and assigned to every pixel of that grayscale value. Image is being processed function "Square Root", which reduces contrast. It is similar to Logarithmic but with a more gradual effect as shown in Fig. 2b). Next operation Gaussian filteringbased on the kernel Fig. 2c). Attenuates the variations of light intensity in the neighborhood of a pixel. The Gaussian kernel has the following model: a d c b e × e b c d a (5×5), where a, b, c and d are integers. Next operation is second Gaussian filtering with the same parameters Fig. 2d). Hereinafter, operation And Performs a logical AND operation between the original input image and a constant or another image stored in the buffer Fig. 2e). This is a bit-wise operation. This is a bit-wise operation. The result is a clean image of the edge of which we define with a Canny filter Fig. 2f).



a) test images.

b) processed function "Square Root"

c) operation "Gaussian filtering"

d) second "Gaussian filtering"

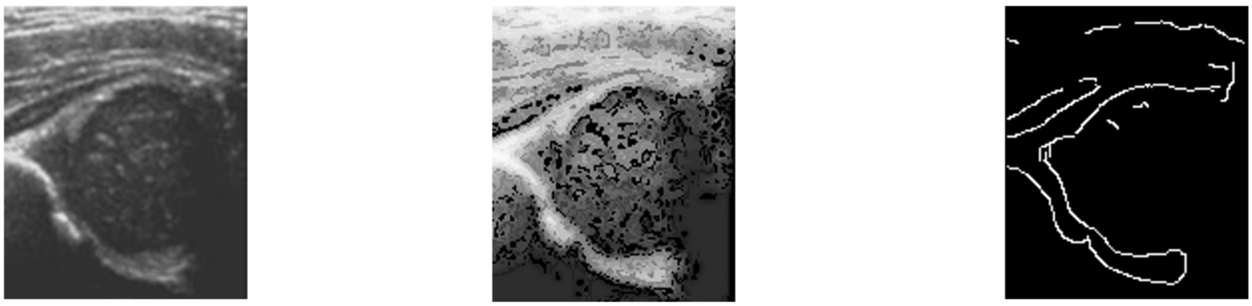
e) logical AND operation between the original input image and two another images from operations Gaussian filtering stored in the buffer.

f) the edge image processing with a Canny filter.

Figure 2. The filtering algorithm of speckle noise of test images with varying degrees of noisiness.

In order to determine the dependence of parametrization error on object size and noise level, standard test images of correct geometric figures (squares of 15×15, 25×25, 35×35, 45×45, 55×55) were used. The reference images have a thickness of contour lines of 1 pixel, so their parameters can be determined with a maximum error of 0.5 pixels. Since the real image of the ultrasound is weak contrast and contains speckle noise, for the most approximate reproduction of the features of the real image of the ultrasound, the reference images were blurred, after which they were superimposed on artificially generated speckle noise with SNR of 0.05, 0.1, 0 , 15, 0.2, 0.25, respectively. For blurring and noise generation, standard functions of the Image Processing toolbox of the Matlab environment are used.

In Fig. 3 processing of the ultrasound image of the hip joint by the proposed method is shown.



a) ultrasound image of a hip joint (original image)

b) logical AND operation of the original input image and two another images obtained by Gaussian filtering.

c) the edges obtained by Canny filtering.

Figure 3. The filtering of speckle noise of an ultrasound image of the hip dysplasia obtained by the method proposed.

4. CONCLUSIONS

A review of the methods of filtering ultrasound images on the example of hip dysplasia images has been presented, their advantages and disadvantages are shown. Demonstrated ways of computer diagnostics of hip dysplasia development. The method of filtration of the speckle noise of ultrasonic images of the hip dysplasia was proposed. The proposed method focuses on Gaussian blur effects, we used this blur method to build an algorithm and demonstrate the simulation results on test images. The idea of the method is that performs a logical AND operation between the original input image and two another images processed Gaussian filtering. The algorithm was tested on the tested images, as well as on real ultrasound images of hip dysplasia. In order to determine the dependence of parametrization error on object size and noise level, standard test images of correct geometric figures (squares of the size of 15×15, 25×25, 35×35, 45×45 and 55×55 pixels) were used. For the most approximate reproduction of the features of the real image of the ultrasound, the reference images were blurred, after which they were superimposed on artificially generated speckle noise with MSE 0.05, 0.1, 0, 15, 0.2, 0.25, respectively. The modeling used the standard functions of the Matlab Image Processing toolbox and the NI Vision Assistant package.

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