Digital ultrasound image processing method with an example of a hip joint condition study

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ABSTRACT

Medical and biological images have different physical natures. A person-operator can perceive them in different ways. Therefore, an important task is the adaptation of the image processing process to a specific user, that is, to a narrow task that is solved by the consumer of information. It is often not enough to present an object to an observer with the help of an ideal display system, since the information required for image analysis in order to search and identify objects, the determination of various quantitative characteristics can be manifested only as a result of digital processing. Based on the above, the paper proposes an automated method for extracting the contours of ultrasound images using the example of studying the state of the hip joint. This method makes it possible to construct conventional lines on the image of the hip joint in an automated mode with minimal expenditure of resources and subsequently to calculate the values of certain angular indicators, and using known methods of studying the condition of the hip joint, to estimate its degree of dysplasia. By automating the process, the reliability of diagnostics can be increased.

Keywords: image processing, modeling, filtering, contrast, selection of the contour on the image, dysplasia, condition of the hip joint, ultrasound, conditional lines.

1. INTRODUCTION

The problem of the consequences of diseases of the musculoskeletal system occupies a leading place in modern pediatric orthopedics and traumatology. Among the deformities of the musculoskeletal system, the most common is hip dysplasia, which is an abnormality of the hip joint when the socket part does not sufficiently cover the ball part, which leads to an increased risk of dislocation of the joint. Dysplasia of the hip joint is a congenital disorder in the structure of the hip joint that occurs due to improper development of the joint. The disease develops when the joint has not formed normally, so it does not work properly.

3% of children are diagnosed with hip dysplasia after birth. Pathology is diagnosed 6 times more often in girls. Therefore, already in the first hours of life, the child must be examined by a pediatric orthopedic traumatologist. Therefore, in order to prevent the negative consequences of the pathology, it is necessary to diagnose and start treatment in time.

A preliminary diagnosis of dysplasia is sometimes made in the first hours after birth. The doctor must examine the newborn to make sure that everything is fine with the baby. Palpation and examination of the baby is carried out after feeding in a calm environment.

To confirm the diagnosis, an additional study is prescribed, which includes such procedures as ultrasound examination (ultrasound) (to determine the cause and localization of disorders), radiography (for adults and children over one year), computer tomography (to assess the state of the bone-ligamentous apparatus).

The use of the X-ray method is associated with radiation exposure, which does not allow its use in children under the age of three months. In addition, the radiograph does not show non-ossified structures - parts of the head of the femur, the

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roof of the acetabulum, which make up the majority of these anatomical formations in children of the first year of life. The consequence of this is the impossibility of detecting disorders of enchondral formation, which is sometimes the main manifestation of hip dysplasia[1,2,3].

Although ultrasound equipment is widely available, proper practice and experience are required to obtain accurate ultrasound results. Despite the fact that the experience of using hip joint ultrasound in pediatrics is growing, this study may not always be accessible and convenient, and only an experienced doctor can make a reliable diagnosis based on visual observation and classify the type of dysplasia according to known methods[4,5].

Today, the main methods of ultrasound assessment of the state of the hip displasia are the methods of Graf, Rosendahl, Harke and Morin, Terjesen, and Dahlström. But they do not have a high reliability of diagnosis, since they are performed manually[6,7]. The result of the diagnosis mainly depends on the doctor's qualifications, since during the examination there may be an incorrect visualization of the anatomical landmarks of the hip joint, made when the child is in the wrong position[8]. This leads to the impossibility of correct measurement of angular indicators, and there is also a sufficiently large error that occurs when manually determining angles on an ultrasound image noisy with speckle noise[9].

Since the bone system is not formed in small children, a special marking method is used for decoding. Conventional lines are drawn on pictures taken in frontal projection to obtain angles, the size of which allows determining the degree of joint deformity. Based on the received data, the presence of violations is determined.

Today, in connection with the emergence of new computer technologies, it is possible to automate this process and classify existing dysplasia.

To fulfill the above and the goal set in this work by developing a mathematical model for automating the process of contour selection and drawing conventional lines on the ultrasound image of the hip joint.

2. DIGITAL PROCESSING OF AN ULTRASOUND IMAGE ON THE EXAMPLE OF A STUDY OF THE STATE OF THE HIP JOINT

Extraction of contours and image filtering is a very important part for high-precision medical operations, such as operations on the heart and brain of a person, where maximum precision of actions and understanding of exactly where certain medical procedures need to be done in order not to harm the patient are required. This also applies to ultrasound images. Therefore, for the automated application of conventional lines on the ultrasound image of an object, it is necessary to highlight the contour of this object.

The simplest method of extracting the primary contour of the image is threshold processing, if the intensity of a pixel is above a certain threshold, then the pixel takes the value of a logical unit, if it is below the threshold, then the logical value of zero. But this approach can be applied only for images with a uniform background, and the intensity values of the objects take the same values throughout the image. The studied ultrasound images, as a rule, do not meet the above criteria, have a heterogeneous background and noise, so this method will not give the necessary satisfactory results[10].

The best results are given by operators based on the gradient contour selection method. These operators differ in window size, weighting factors, and registration methods[11].

With processed ultrasound images, it is difficult to distinguish the contour using such methods, since the magnitude of the boundary gradient and noise practically have the same value. In addition, the contour line obtained by this method, although it is continuous, is indistinct and blurred, which practically makes it impossible to automatically select objects and calculate their geometric parameters.

Today, the optimal Kanni detector[12] is widely used for image contour selection. The Canny edge detector algorithm is not limited to computing the gradient of a smoothed image. Only the maximum points of the image gradient remain in the contour, and the non-maximum points lying next to the border are removed. It also uses path direction information to eliminate points near the boundary and not break the boundary itself. The scale of the Gaussian sigma determines the amount of noise suppression: the wider the Gaussian, the greater the smoothing effect. But increasing this scale reduces the accuracy of boundary localization. Since the detector consists of several algorithms (LoG and Canny), the computational costs increase dramatically.

The advantages of the Canny detector are high resistance to noise due to the use of the Gaussian method, which gives a better quality of image segmentation, and also remains sensitive to low-contrast images. The main disadvantages of detectors of this type are the high complexity of calculations and long processing time, the selection of spurious contours, with slight changes in intensity, the detectors do not work, since many spurious contours appear in the image, and the small value of the gradient does not allow you to quickly set the appropriate threshold level and identify the change intensity as a contour[24].

The paper proposes an approach that involves the use of global binarization of images using the Otsu's method. This method is based on automatically calculating the threshold image, or reducing the gray image to a binary image. The algorithm assumes that the image contains two classes of pixels, the following bi-modal histogram: foreground pixels and background pixels. Then the optimal threshold separating the two classes is calculated so that their combined range (cluster variance) is minimal or equal (because the sum of pairwise squared distances is constant) so that their intercluster variance is maximal. Therefore, Otsu's method is an approximate one-dimensional discrete analogue of Fisher's discriminant analysis. This method is the best way to find a global image threshold and is self-explanatory and suitable for most cases where a global image threshold is desired. The advantages of Ottsu's method are ease of implementation, adaptation to various images by choosing the optimal threshold, and fast execution time. The disadvantages of the method are that the image is sensitive to noise. It can be segmented for only one purpose, when the ratio of the size of the object to the background is large, and the variance function between classes can show double or multiple peaks[13]. Therefore, for further work with such an image, it is necessary to select a fragment of the image of the hip and filter the image in order to reduce the noise component. The recorded ultrasound image of the hip joint is shown in Figure 1a.

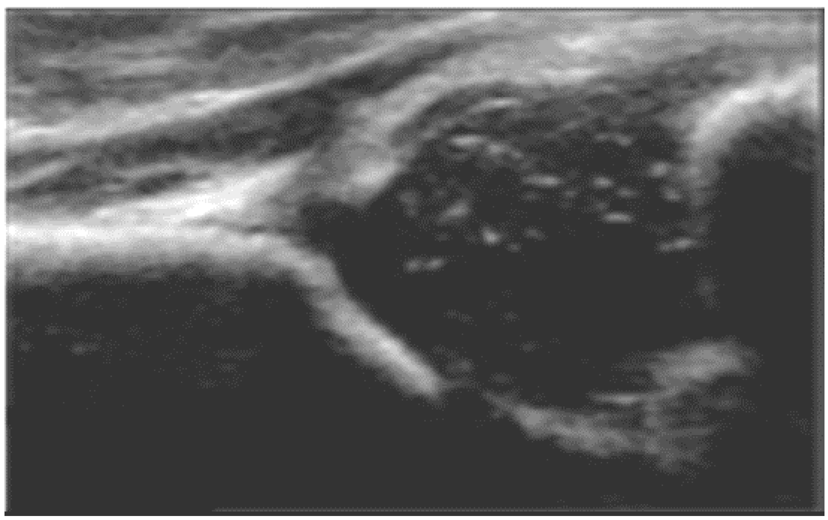


Figure 1. Ultrasound image of the hip joint.

Today, there are two main approaches aimed at suppressing noise in ultrasound images: frame-by-frame averaging and post-processing. Each of these approaches has disadvantages:

- frame averaging reduces the real frequency of frame changes, since the image obtained as a result of processing is a superposition of several processed frames. Therefore, the image of moving objects, when several frames are superimposed on each other, can be indistinct, blurred;

- the result of the post-processing filter is a possible loss of detail and an increase in processing time, although the "readability" of the processed image is better than that of the original[14].

Since the hip joint image can be considered static and in order to simplify the further processing algorithm, the image filtering of the first approach was used, namely, the median filter was applied. This filter is usually used for filtering mainly impulse noises and has become widespread due to its reliability and the ability to preserve the contour. The median filter uses the median value of the pixel intensity within an area, thus creating less blur in images than other filters. This filter also requires the user to set the size of the sliding window. For this algorithm, different sizes of image processing windows 3, 5, 7 and 9 were used. In Fig. 2 shows a selected fragment of the hip joint image processed by a median filter with a window size of 3×3.

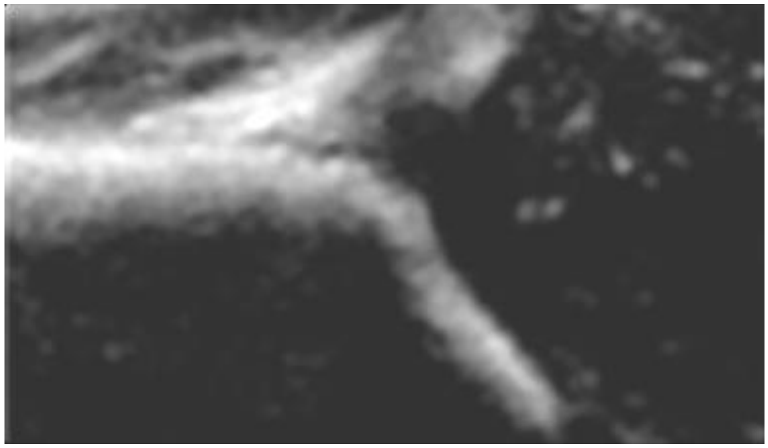
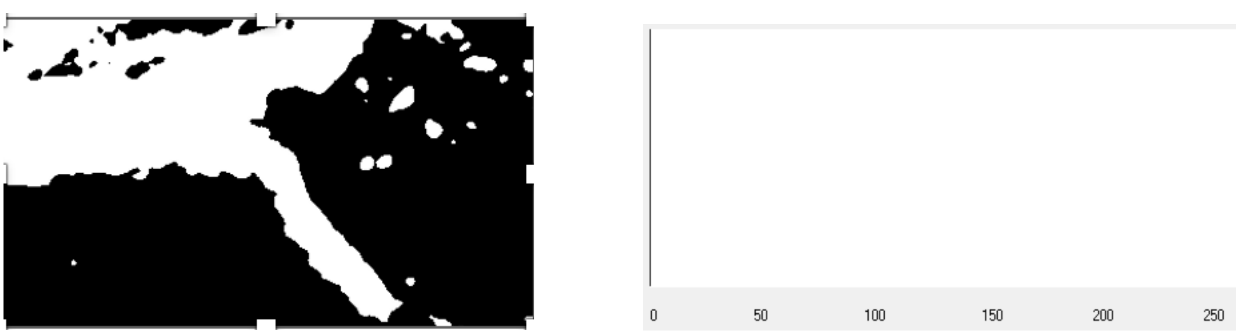


Figure 2. Selected fragment of the hip image, proves with a 3x3 window.

We will perform linear contrast of the hip joint image (Fig. 3)[15]. Such contrast is used to match the dynamic range of the input image signal and the dynamic range of brightness of the display device. If 1 byte (8 bits) of the memory device is allocated for the digital value of each image reading, then the input or output signals can acquire one of 256 values. When comparing two images (input and output) of the hip, a much better visual quality of the processed image is established.

Figure 3. Linear contrast of hip image.

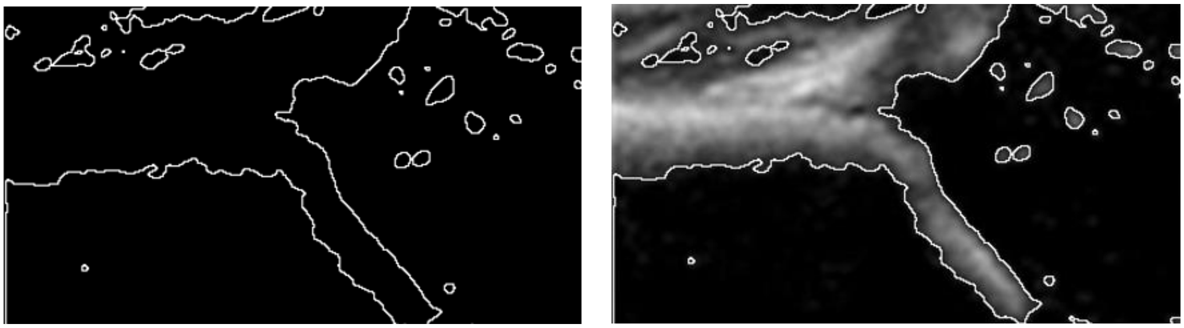
Using the Otsu's method, we will obtain a binary image of a fragment of the hip joint (Fig. 4a). The histogram of such an image contains only two types of pixels - with zero and maximum brightness (Fig. 4b).



a) b)

Figure 4. Binary hip image with Otsu's method (4a), histogram image (4b)

The use of such a hip joint image significantly simplifies the selection of its contour and does not require the use of complex methods. In fig. 5a shows the contour image of the hip using the Roberts operator. At this stage of the algorithm, any known contour selection operators can be used. In fig. 5b shows the contoured image of hip.



a) b)

Figure 5. Contour image of hip joint with Roberts operator (a), contoured image (b)

If the information obtained on the basis of the image in Fig. 5 is not enough, then, using the tool for selection of rectangular areas on the image, you can select areas of the image in which conditional lines or points of this object will be formed on the image. In our case, it concerns the bony triangle of the acetabulum and the roof of the cartilage to assess the state of the hip joint. For this purpose, the Rectangular Marquee or Polygonal Lasso tool is used, which is widely available in graphic editors. In fig. 6 shows an example of a hip joint image with highlighted areas.

Using the data array of the contour lines of the selected areas and known approximation methods, such as the method of least squares, and linear interpolation, it is possible to select the best polynomial trend lines as shown in Fig. 7. Analogously, polynomial curves can be obtained if necessary.

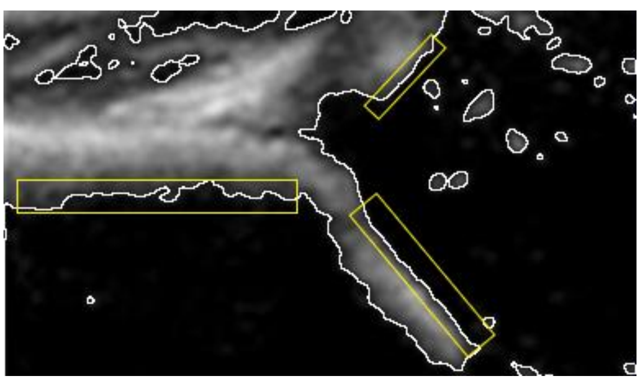


Figure 6. Hip joint image with selected areas

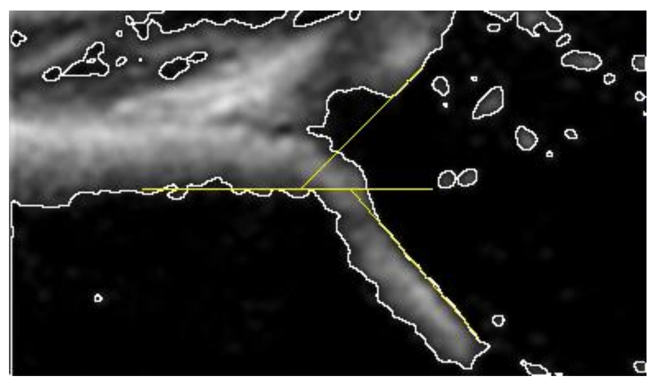


Figure 7. Applying conventional lines on the image of the hip joint

3. CONCLUSION

The paper proposes an automated method of processing ultrasound images using the example of a child's hip joint, which makes it possible to improve the image itself, highlight hidden objects, and determine their geometric parameters. The method includes such steps as capturing a specific region of the hip joint, performing image filtering and linear contrast, and converting the image to binary using the Otzu operator. This makes it possible to obtain an ideal contour and subsequently contour the object in the image, draw conditional lines and calculate angular indicators according to known methods.

The proposed detection method has not only sufficiently high accuracy, but also high speed with minimal use of resources.

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