

ОБРАБОТКА ИЗОБРАЖЕНИЙ, РАСПОЗНАВАНИЕ ОБРАЗОВ

Improvements of programing methods for finding reference lines on X-ray images

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Abstract

The paper gives an overview of the algorithms developed to obtain reference lines and angles on X-ray images. These geometrical characteristics are used in the medical analysis of human joints. We propose the algorithm's modifications based on the analysis of numerous X-ray images. These modifications allowed obtaining a great increase in calculation speed and the improvement of final results quality given by the corresponding application. They also lead to a significant reduction of manual tuning of the program, arising only in the rare cases when the properties of given images differ significantly from the mean ones.

Keywords: reference lines and angles, Canny edge detection algorithm, reference lines, image processing, X-ray images, pattern recognition.

Citation: Al-Temimi AMS, Pilidi VS. Improvements of programing methods for finding reference lines on X-ray images. *Computer Optics* 2019; 43(3): 397-401. DOI: 10.18287/2412-6179-2019-43-3-397-401.

Acknowledgements: The authors are grateful to the experts from Iraq – Al-Abayechi Sinan Adnan (Medicine Iraqi Board of Orthopedic Surgery) and Bassam Faleh Hassan (Medicine Arabic Board of Diagnostic Radiology) who attracted the attention to this investigation. They provided us with X-ray materials, gave important advice connected with the implementation and discussed the obtained results.

Introduction

Computer methods of analyzing medical information attract the attention of numerous scientists, we mention here e.g. [1–6].

Wide usage of X-ray methods for diagnostics is connected with their high quality, wide presence of corresponding equipment, comparative simplicity and cheapness of the investigation. Knee and elbow joints take an important place among these investigations.

In this paper, we give modifications of the boundary detection algorithm described in [7, 8] and make some essential improvements. The mentioned modifications are based in the thorough analysis of the X-ray images of the domains under consideration.

Areas of applications of X-ray diagnostic methods are constantly expanding. One of the relatively new approaches in diagnosis is the method of reference lines and angles [9–12]. Based on the evaluations by the experts, it is used to analyze possible deviations in the human extremities. In the case of deviations, it permits to give numerical estimates and to obtain recommendations for planning reconstructive treatment.

The modifications described below can significantly improve results obtained by the applications created on their basis (speed of the work, quality of the obtained results). They essentially decrease the number of parameters needed for the manual tuning of the program and significantly decrease the number of cases when such tuning is necessary.

Main part

In order to identify and estimate the degree of deformities of the extremities, there are defined geometrical ob-

jects, called anatomical and mechanical axes of long bones, anatomical and mechanical angles. Normally, these reference lines intersect each other at certain points and at certain angles. If these indicators are out of the accepted normal boundaries, the surgeon may draw corresponding conclusions.

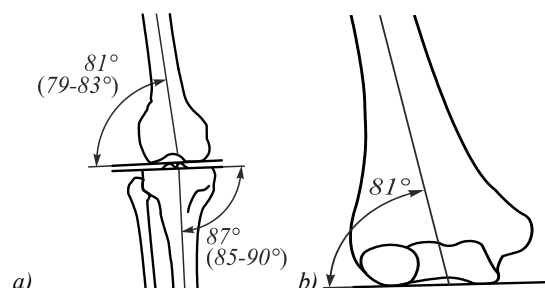


Fig. 1. Reference lines and angles, knee joint (a), elbow joint (b)

In the following, we describe briefly the scheme of the analysis used in the applications created by us for automatic obtaining of the characteristics mentioned above.

Next, we discuss the steps of the used algorithms and present some results on the modification of the proposed algorithms in order to increase the speed of their work and improve the quality of the obtained results. More exactly, we analyze the methods to increase the speed of image filtering and to optimize parameters for the Canny algorithm.

In the program [13] developed on the basis of the algorithms described in [7,8], the low-pass filter [14] was the first step. A simple filter averaging over a square mask was used. The size of the mask was determined after analysis of a large number of X-ray images. It turned out that the qual-

ity of the obtained result depends essentially on a number of factors, particularly, the scale of the image.

On the next step, we use the Canny edge detector [15]. It should be noted that the use of a low-pass filter at the previous stage of processing significantly improves the quality of the results obtained at this stage. We would like to point out here that the usage of the filter is necessary to obtain a more accurate result. In the Fig. 2 it is shown that without the filter there was a loss of essential information.

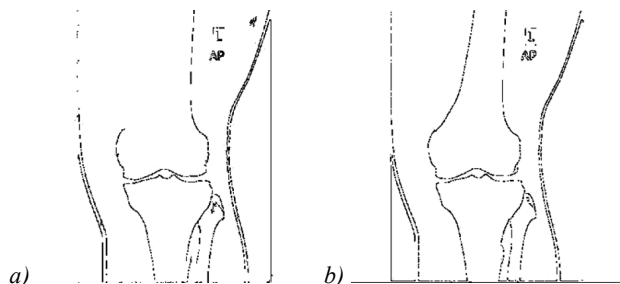


Fig. 2. Canny detection without the filter (a), Canny detection with the filter (b)

Then we use dilation operation [14] to eliminate gaps in the boundaries. After that, there is used the watershed segmentation algorithm [16]. Only large contours are the subject of the further consideration, so the small ones are eliminated by comparing their perimeters with the threshold value (this value was obtained experimentally and equals 200 pixels), it may be changed in the program settings.

For the remaining regions, the centers of the mass for all regions are calculated. These points are used as the markers for the segmentation algorithm at the next step (see Fig. 3).

We make a mask from the obtained areas, this mask quite accurately corresponds to the contours of the bones, such that the remained areas in the space that are not parts of the bones are not included.

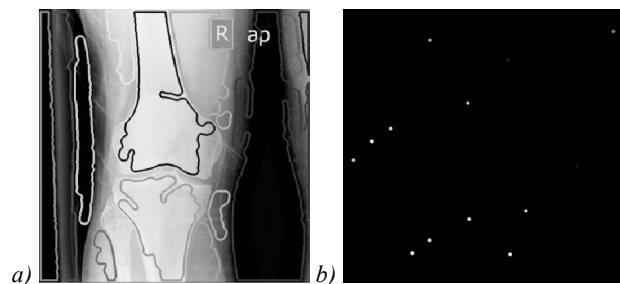


Fig. 3. Large contours when applying watershed algorithm (a), the centers of mass for all regions (b)

The segmentation algorithm for watersheds starts with the mask obtained in the previous step. For each of the areas received, it is determined whether it contains a point of interest [7, 8].

After applying the segmentation algorithm from the obtained areas, every region is labelled by the mark different from the others. Using these marks, we select one or two regions containing the points of interest. In the case of the knee there are two points because we analyze two bones, but in the case of the elbow, there is only one point.

The location of these points of interest may be changed in the program settings as well.

Then the Canny edge detector is applied again for the second time to analyze the joint area.

On the next step, the picture is improved using erosion, opening and dilatation morphological operations [14]. There are eliminated errors in the positions of the contours.

Thus, the contours of the femur and tibia or humerus permit us to obtain the reference lines and the angles of the knee or elbow joint.

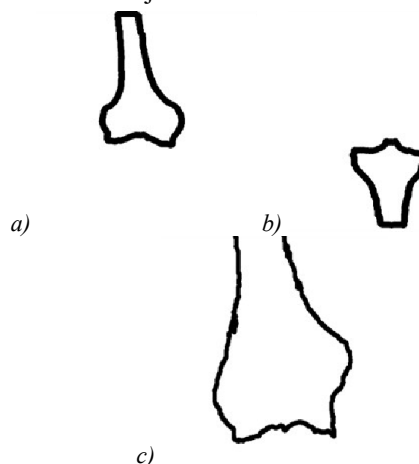


Fig. 4. The contours of femur (a), tibia (b) and humerus (c)

In this work, we consider some modifications of the work mentioned above, the aim of the modifications is to obtain better quality, to decrease the number of tuning parameters of the program and to reduce essentially the need of correction of the remaining parameters.

The time of preliminary filtering using the standard approach is given in the Table 1 below.

Table 1. Runtime in milliseconds for averaging pixel intensities with the different size of the mask

Number of attempts	Size of kernel	Average runtime
1	3×3	203 ms
2	7×7	210 ms
3	10×10	230 ms
4	12×12	239 ms
5	19×19	401 ms

The first modification is connected with another method of preliminary filtering which improves the performance of the program.

We recall first the scheme of constructing the so-called integral image (summed-area table) [17–19]. Denote by $I(x, y)$ the intensity of the image at the point (x, y) . We define the array of the same dimensions as the image itself by the following formula (1)

$$T(x, y) = \sum I(x', y'), \tag{1}$$

where the summation is over all the values of the arguments satisfying conditions $x' \leq x, y' \leq y$. This auxiliary array permits to find the sum of the intensities in any rectangular image fragment using three addition-subtraction operations.

Suppose that we use $k \times k$ mask in the case of an $m \times n$ image. In the standard approach, we need $k^2 mn$ additions and mn divisions.

Calculation using the integral tables method needs mn preliminary additions, $3mn$ additions-subtractions and the same number of divisions as in the previous approach. This approach needs only $4mn$ additions-subtractions and needs essentially fewer operations because the value $k=7$ is the most appropriate for the overwhelming majority of images.

Another advantage of this approach consists in the even greater reduction of the number of calculations in the case of changing the mask size by the user because the integral tables do not need to be recalculated.

The execution time of averaging the pixel intensities using the integral image is approximately 78 milliseconds and does not depend on the size of the filter kernel. The time is 2–5 times less than in the previous method (see Table 1).

Another implemented modification is the method for finding the threshold values of the Canny edge detector. This algorithm needs two different thresholds (for detecting the so-called strong and weak edges). The quality of its output depends significantly on these values. As we mentioned above, the Canny edge detector is to be used twice, and here we speak about the first (global) step.

We found that these thresholds should vary from one image to another, being dependent on the properties of the image. If we use some constant values for these thresholds or leave their choice to the user, it can lead to deterioration in the quality of the obtained results or the significant increase in the runtime.

In a number of papers there were proposed various, often rather complicated methods for determining these thresholds (see, e.g. [20]).

Our experiments show that for the current type of the images, it is possible to find these thresholds automatically, using only the statistical characteristics of the image. This significantly improves the quality of boundary detection.

To speed up the program in the case of sufficient uniformity of the analyzed images, an attempt was made to find an easy way to detect these boundaries. It was suggested that these thresholds can be given in the form $M \pm k\sigma$, where M is the average value of the filtered image, σ is the corresponding standard deviation, K is the coefficient found from the results of the experiments. After series of experiments, it was found that the best results for images of the class under consideration are obtained with the values K ranging from 0.18 to 0.25.

The value M is obtained directly from the integral table because this table contains the sum of all intensities. The standard deviation is found by the formula $\sigma = \sqrt{M_2 - M^2}$ where M_2 is the average value of the squares of intensities. The method of integral table permits to optimize calculation of the value M_2 . The intensities take integer values from 0 to 255. In the process of building the integral image, there is counted the numbers of each value. If the value t ($1 \leq t \leq 255$) appears k_t times then

$$M_2 = \frac{1}{mn} \sum_{t=1}^{255} k_t t^2,$$

where m, n are the sizes of the image under consideration.

The following table contains results of the experiments with two different approaches for finding thresholds of Canny detection. There was taken the value $k=0.25$.

The experiments show that the new method gives essentially different values of the thresholds and there are obtained much better results than in the case of fixed thresholds.

The results were compared visually. There was also compared the number of pixels obtained after the work of the old method and the new one. The experiments show that the important details were not damaged in the both cases under consideration, but in the new method the pixels representing the boundary of the contours are more accurate and the number of unnecessary details radically decreases (see Fig. 5).

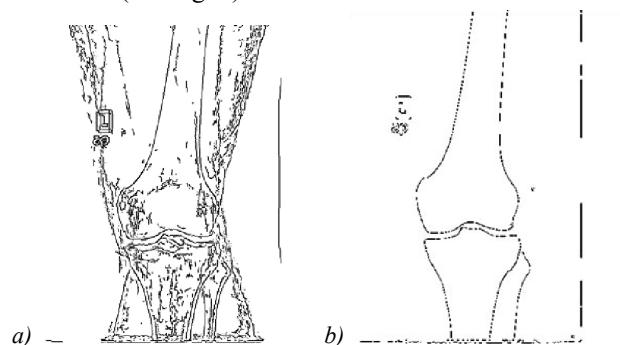


Fig. 5. Results of the Canny detector using the default thresholds (a), and the adaptive thresholds (b)

We found that during the second usage of the Canny algorithm local analysis necessary for the thorough identification of details in the joint areas permits to obtain satisfactory results with the constant values of the thresholds which were obtained after experiments. The possibility to apply universal thresholds, in this case, can be explained by the substantially greater homogeneity of the fragments analyzed at this stage.

Table 2. The result of implementation for finding the threshold values of Canny algorithm $k = 0.25$

Image number	Number of pixels (old method)	Min. auto threshold	Max. auto threshold	Number of pixels (new method)
1	10437	1	40	6652
2	8192	1	30	6983
3	9946	1	39	5855
4	10443	10	47	4530
5	11041	2	49	4774
6	13040	6	49	6558
7	9362	3	53	4861
8	9793	3	50	5342
9	22237	12	39	9525
10	12506	4	43	7900
11	9578	15	50	6815
12	10360	1	36	7583
13	10051	2	38	7407
14	9052	4	38	5323
15	9301	5	34	6683
16	9379	1	41	5361
17	8089	1	35	6519
18	14724	1	34	8963
19	8499	5	50	3921
20	11820	1	40	6327

The scheme of the algorithm is given in the Fig. 6.

Implementation

Program based on the scheme of analysis described above was implemented in the Imam Ali General Hospital in the city of Baghdad. It used the images obtained from three X-ray devices having slightly different characteristics. It analyzed X-ray images obtained from 30 patients.

The program was used without manual tuning, the obtained results were 100% successful. It turned out that the program permits to find abnormalities in the cases when they were not seen by the visual analysis.

We mention that for the application using the algorithm from [7] there were found several X-ray images analysis of which needed manual tuning. The application following the algorithm described above was able to process these images without such tuning.

Conclusion

The proposed methods for optimizing the algorithm based on the numerous experiments, significantly improve the quality and reliability of the obtained results.

The processing time of the program is less than half a second, which is sufficient for a comfortable use.

The testing results of the application based on this algorithm show that the analysis of the X-ray image gives essential information about the state of the analyzed region and permits in some cases to find abnormalities in the human joints that the specialist is unable to find by the visual analysis.

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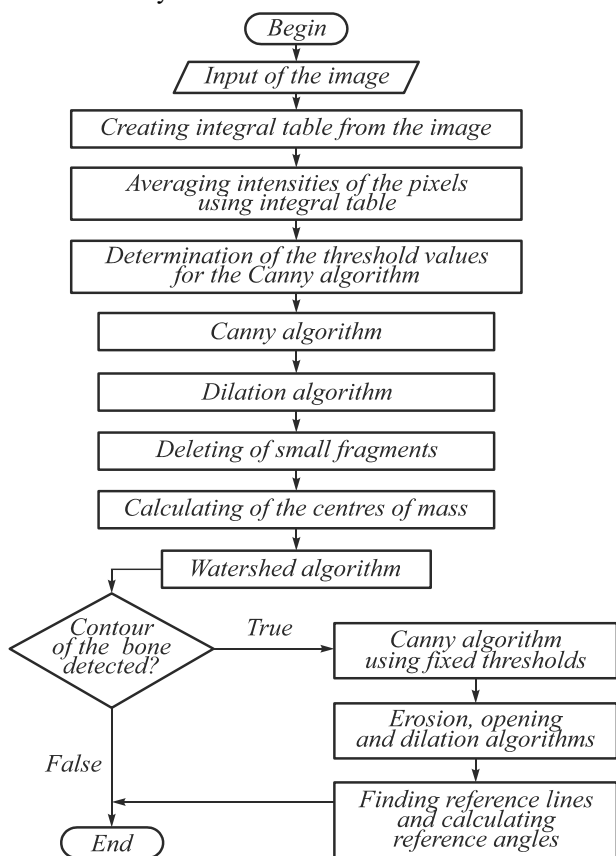


Fig. 6. Scheme of the algorithm

The algorithm developed in this paper can be applied for analysis of X-ray images in similar cases.

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Received October 2, 2018. The final version – March 5, 2019.
