A method for locating the iliac crests based on the fuzzy Hough transform

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Abstract— *In this paper we present a method based on the fuzzy Hough transform to locate the iliac crests in posteroanterior radiographs. Firstly, a Canny edge detector is applied to the X-ray images in order to obtain an edge map. Then, the fuzzy Hough transform is used in combination with several constraints extracted from our domain knowledge. At the bottom of the radiograph we search for two circular arcs, as we can represent the shape of the iliac crests by means of these curves. Locating the iliac crests can be useful for a later processing of the X-rays in order to obtain a fully automated segmentation of the whole spine.*

Keywords— Computer-aided diagnosis, fuzzy Hough transform, medical imaging, X-rays.

1 Introduction

Computer-aided diagnosis is increasing its importance in healthcare. This kind of systems can help physicians to perform routine tasks that require a long training and a great amount of time, and can provide more accurate and consistent measures that may improve the diagnostic process.

Modern medical imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) provide images of high quality which can help physicians enormously in diagnostic process. However, these techniques are usually expensive and give patients high doses of radiation. Therefore, they are not suitable for all diagnoses and, although X-rays do not provide as much quality as the other ones, they are widely used in diagnosis of many diseases.

Much research has been done to segment anatomical structures in CT and MRI. Nevertheless, X-rays have not been as widely studied as the other ones due to its lower quality. In our work we use X-ray images because they are extensively used in diagnosing scoliosis, which is the problem we are focused on.

Scoliosis is a three-dimensional deformation of the spine that produces vertebral rotation and crushing, and lateral curvature. It is typically classified as congenital (caused by vertebral anomalies present at birth), idiopathic (sub-classified as infantile, juvenile, adolescent or adult according to the time when the onset occurred) or as a secondary symptom of another condition, such as cerebral palsy, spinal muscular atrophy or due to a physical trauma.

Diagnosis of scoliosis is performed by calculating Cobb angle ([1]) manually on X-rays. Automatic measure of Cobb angle could improve diagnosis since it can provide more reliable and consistent measures. In order to assess Cobb angle automatically we need to segment the spine accurately and, as we will see afterwards, the proposed method can be useful to do so.

The iliac crest is the long and curved upper border of the wing of the ilium. According to a study performed by Render in [2], the line connecting the iliac crests intersects the spine at the level of the fourth lumbar vertebra or the interspace between the fourth and the fifth lumbar vertebra in 78.5% of cases, while the point of intersection was lower than the fourth lumbar vertebra in 17.8% and at the level of the interspace between the third and the fourth lumbar vertebra in 3.7%. We are interested in locating these anatomical structures as we can use them as a reference to initialise a segmentation algorithm that is intended to segment the whole spine. In the same way, this reference point will be useful to label the vertebrae found by the segmentation algorithm, since we can use the results of Render.

In this work, we have used full-length standing posteroanterior X-rays. The pictures were acquired from a PACS (Picture Archiving and Communication System) as DICOM (Digital Imaging and COmmunication in Medicine) files with 5700×2400 pixels of resolution. The problem with this kind of images is the presence of noise and distortions due to its acquisition process, that makes difficult to detect and identify the anatomical structures present in the X-rays accurately. Other important problems are poor contrast and low visibility of some details in the images. In order to deal with these problems, first of all we have to preprocess the images to obtain new ones with less quantity of noise and, as far as possible, better visibility than the initial ones.

The rest of the paper is organised as follows: in section 2 we describe the foundations and the operation of the fuzzy Hough transform. In section 3 we present our method for locating the iliac crests in posteroanterior radiographs and, in section 4, we discuss the results achieved by it. Finally, in section 5, we comment some aspects of our future work related to this paper.

2 The fuzzy Hough transform

The Hough transform (HT) was originally proposed as a technique to detect straight lines by Hough in 1962 ([3]). It was extended to detect general curves with known analytical expressions by Duda and Hart in [4] and, later, Ballard proposed a new extension in [5] to detect any curve although its expression was not known. In this work we use the fuzzy Hough transform (FHT), another extension of the original algorithm developed by Han *et al.* in [6].

A straight line can be represented as $\rho = x\cos\theta + y\sin\theta$, where θ is the angle of the vector from the origin to the closest point of the line, ρ is the lowest distance between the line and the origin and (x, y) are the coordinates of a point in the image space. In that way, a line is defined by these two parameters ρ

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and θ. Similarly, a circle and other curves can be represented by its parameters. The main goal of the algorithm is to detect shapes by checking which points in the edge map belong to the curve defined by a certain point in the parameter space. This is done by mapping the image space to the parameter space, where each point defines a different curve. By doing so we simplify the problem to locate a peak in an accumulator array.

In the original HT, the value at a point of the parameter space is the number of points in the image space that occur strictly on the shape defined by this point of the parameter space. There is no difference between a point being far from the ideal line or being just a little off it. Because of this, with the HT is difficult to detect approximate shapes that may appear in noisy environments due to the noise itself, or due to the not accurate edge detection performed by the feature detector. Fuzzy theory can help to deal with the detection of those approximate shapes.

We have assumed that we can represent the shape of the iliac crest by two circular arcs. However, the iliac crest is not exactly a circular arc, although it is close to. Because of this, the results obtained by applying the conventional HT to the X-rays are not accurate, so we propose the use of the FHT in order to achieve better results. In section 4 we make a comparison between both techniques based on the results achieved by them.

The main idea in the FHT is that each edge point contributes more or less to one point in the parameter space depending on its distance from the ideal curve defined by this point. To do this, once the accumulator is computed, Han *et al.* proposed to convolve it with the membership function

$$g(d) = \begin{cases} ke^{-d^2/\sigma^2} & if\ d < R \\ 0 & otherwise \end{cases} . \quad (1)$$

As they proved, when the membership function of fuzzy points is defined as a circle the transforms of those points lying inside it is bounded in the parameter space by r, which is the radius of that membership function. That is true for straight lines and circles and, as we are considering circular arcs in such a way that they are particular instances of circles with some restrictions, we shall use this smoothing function.

In (1) k, σ and R are constants that are chosen empirically and d is the distance between the two points of the image considered. In our case, they are set as $k = 1$, $R = 3$ and $\sigma = 1.3$ in the experiments.

3 The proposed method to locate the iliac crest

In this section we present our method for automated detection of the iliac crest, based upon the fuzzy Hough transform. The method starts with the acquisition of the X-rays and finishes with the location of the iliac crests. Fig. 1 shows the operation of the method. It involves basically the search for circular arcs at the bottom of the radiograph, where the iliac crests are supposed to be, by means of the FHT.

As we have mentioned beforehand, a preprocessing stage is necessary to deal with noise and distortions present in the images. In this work we have used a combination of unsharp masking (UM), adaptive histogram equalisation and median filter to achieve images more suitable to be analysed by a computer vision system.

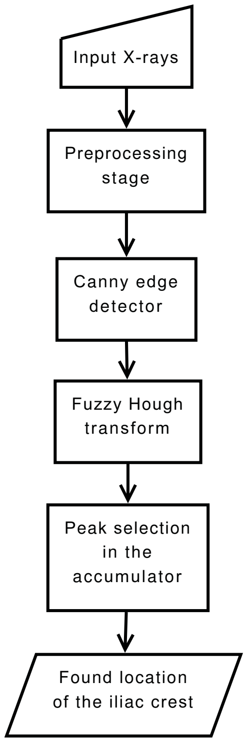

Figure 1: Flowchart of the proposed method to detect the iliac crest

Unsharp masking intends to improve the visibility of images by emphasising smoothed edges while the noise components are suppressed. The effect of the algorithm onto the images is edge sharpening, but usually it tends to reduce its contrast. Because of this, after the unsharp masking procedure we perform adaptive histogram equalisation to enhance it.

In unsharp masking, the high-frequency components of the image are extracted and then are added to the original image. First of all, a slightly blurred version I_{blur} of the image I_{orig} is obtained by convolving it with a Gaussian kernel and then is subtracted from I_{orig} to obtain I_{edge}. After that, I_{edge} is multiplied by a sharpness factor and the result, which contains the enhanced high-frequency components of the image, is then added to I_{orig}.

In our case, the unsharp masking is done by using

$$I_{sharp}(x, y) = I_{orig}(x, y) + 6 \cdot (I_{orig}(x, y) - I_{blur}(x, y)). \quad (2)$$

In (2) $I_{orig}(x, y)$ represents the original image and $I_{blur}(x, y)$ is a blurred version of the original image obtained by convolving $I_{orig}(x, y)$ with a Gaussian kernel of size 5×5 pixels and a variance of 5.

After the unsharp masking, we apply adaptive histogram equalisation to the image in order to enhance the contrast of the resultant image. Adaptive histogram equalisation divides the image into several regions and then distributes pixels values in each region of the image uniformly throughout the grey scale. It is performed in order to achieve a higher contrast for the images by means of the *adaptivehisteq* MATLAB function.

Finally, a median filter of size 11×11 pixels is applied to the image with the *medfilt2* MATLAB function to reduce the presence of impulse noise, naturally present in the X-rays.

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Once the image has been preprocessed, Canny edge detector is applied to it in order to obtain an edge map that will be used as a starting point for the FHT in the locating procedure. The Canny edge detector is one of the most widely used algorithms among all the features detectors. It was proposed by Canny in [7] in 1986. This method consists of several stages: first of all noise reduction is performed by means of a Gaussian filter; then it computes the gradient in every point of the image and discard those ones whose value is under a certain threshold; next, the pixels whose gradient magnitude is not maximum in the gradient direction are suppressed; finally a hysteresis thresholding is performed by using two thresholds to suppress spurious noisy pixels.

We have used the implementation available in MATLAB by means of the $edge$ function, and we have used the default parameters of the function.

In order to apply the FHT we need to identify the parameters that define the considered curve and the equation that relates them. A circular arc is defined by five parameters: the two coordinates of its centre, its radius, its orientation and its angular size. We could use the generalised Hough transform proposed in [5], but this would imply that we would have to use a five-dimensional accumulator. By doing so, the memory and computational requirements of the algorithm would rise enormously. Nevertheless, if we can fix one or more parameters, the requirements will remain reasonable.

In this case, after studying the characteristics of the iliac crests showed in the X-rays, we can assume that the radius of the circular arcs we use to represent them has to be between fifteen and forty pixels. We can also assume that an appropriate orientation for the circular arc could be 0 rad and a suitable angular size for it could be π rad. These assumptions we have made permit us to simplify the original problem reducing its computational requirements, which is one of the major drawbacks of the Hough transform. Instead of using a five-dimensional accumulator we can use a less computational expensive three-dimensional array.

In this work we have used a parametric representation of the circular arc, which allow us to use the parametric equation of the circle by restricting the permitted values for the parametric coordinate between 0 rad and π rad, instead of between 0 rad and 2π rad that we would use if we were searching for a whole circle. Moreover, the parametric representation facilitates the computation of the positions of the accumulator that have to be incremented. Thus, the equation used to describe the circular arc is

$$\begin{aligned} x(t) &= R \cdot \cos(t) + a \\ y(t) &= R \cdot \sin(t) + b \\ t &\in [0, \pi] \end{aligned} \tag{3}$$

where t is the parametric coordinate, R is the radius of the circular arc and (a, b) are the coordinates of the centre of the arc.

Next, we introduce the formal description of our implementation of the FHT:

1. Set the initial values of the accumulator A to 0.
2. For each edge point (x, y), do:
   (a) For each radius R between 15 and 40 pixels, do:
      i. For every $t \in [0, \pi]$, do:
         A. $a = x - R \cdot \cos(t)$
         B. $b = y - R \cdot \sin(t)$
         C. $A[a, b, R] = A[a, b, R] + 1$
3. Convolve the accumulator A with the smoothing function (1).

At this point we can apply the FHT, as we have just described it, to the edge map obtained in the previous step. By doing so, we get an accumulator array where the maximum values represent the most suitable arcs for the given image. We shall use the one hundred biggest ones of those peaks.

After the use of the FHT, several constraints coming from the domain knowledge are applied to the peaks found in the accumulator array to improve the performance of the algorithm.

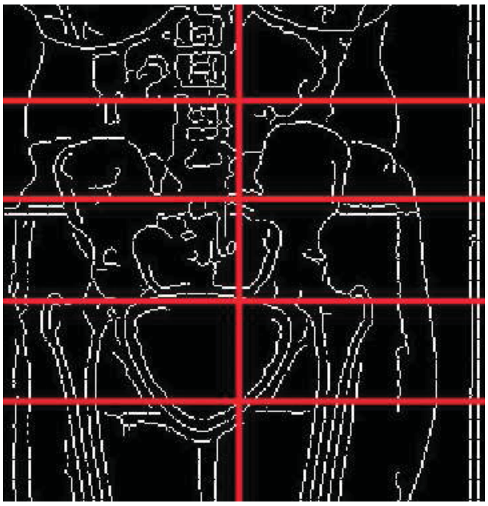

Figure 3: Canny edge map divided into regions to seek local maxima

We divide the lower part of the radiograph into two parts, and we seek the left iliac crest in the left half and the right iliac crest in the right half. Let us consider five regions of equal size within each considered division of the radiograph as we can see in Fig. 3. The search is performed separately in the left and in the right parts of the X-ray. In each region we search for the maximum local peak and record the parameters of the correspondent circular arc. Thus, we have ten local maxima, five for the left part and five for the right part, which represent ten circular arcs that are suitable locations for the iliac crests. We can make twenty five possible couples with those peaks by choosing one from the left and another one from the right.

We can assume that the locations of the left and the right iliac crests are, approximately, at the same height in the X-ray. Let us consider a tolerance factor of 15 pixels. In that case, we can discard those couples of peaks which do not satisfy this criterion. Finally, for the couples of peaks which satisfy the criterion, we add its values and we choose the one with the largest value. Thus, at the end we have a couple of peaks which corresponds to the location of the iliac crests obtained by the method. This process is called "peak selection in the accumulator" in Fig. 1.

We performed several experiments in order to choose the most appropriate values for the tolerance factor and the number of regions in terms of its performance.

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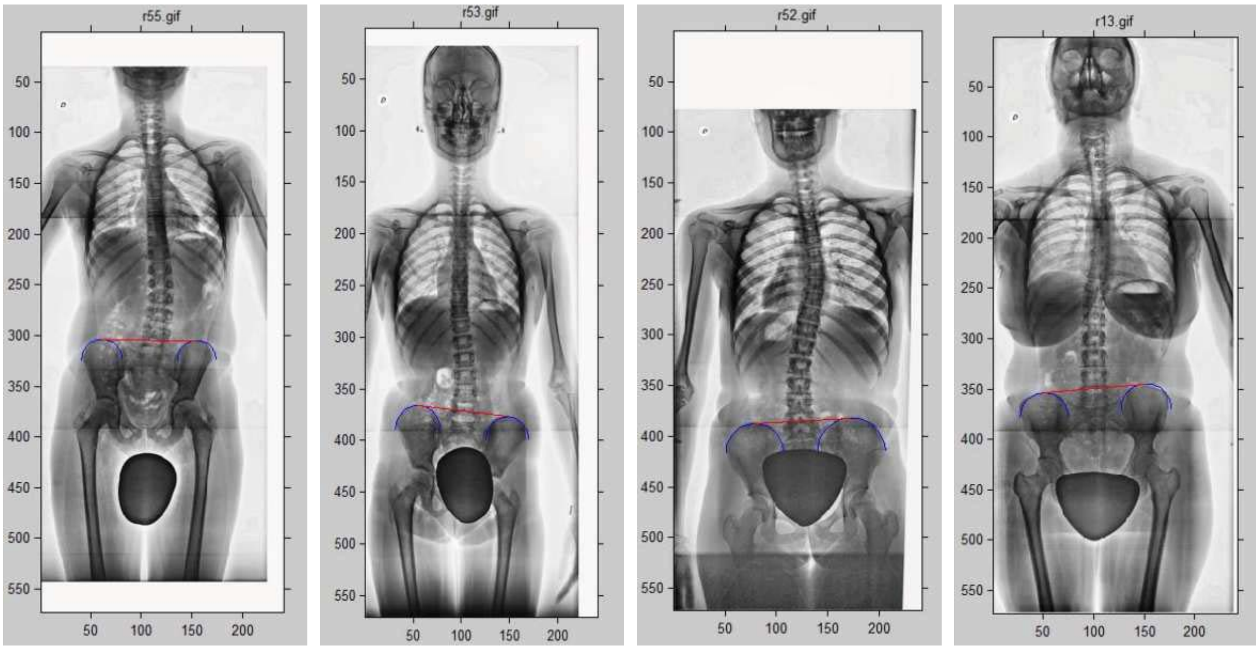
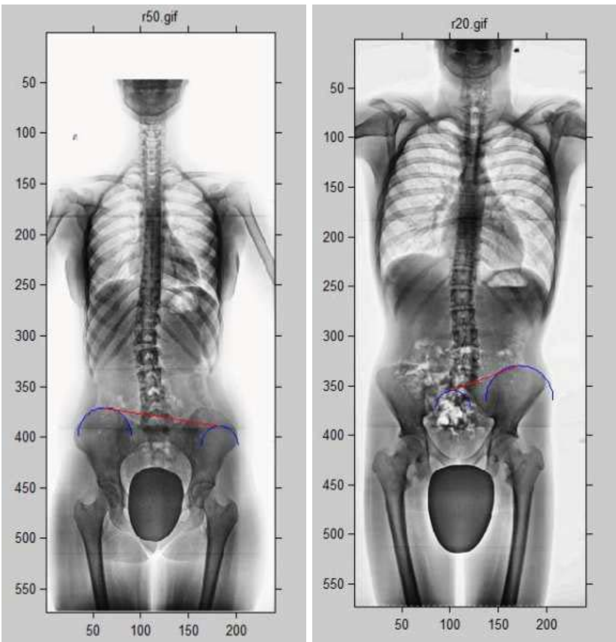
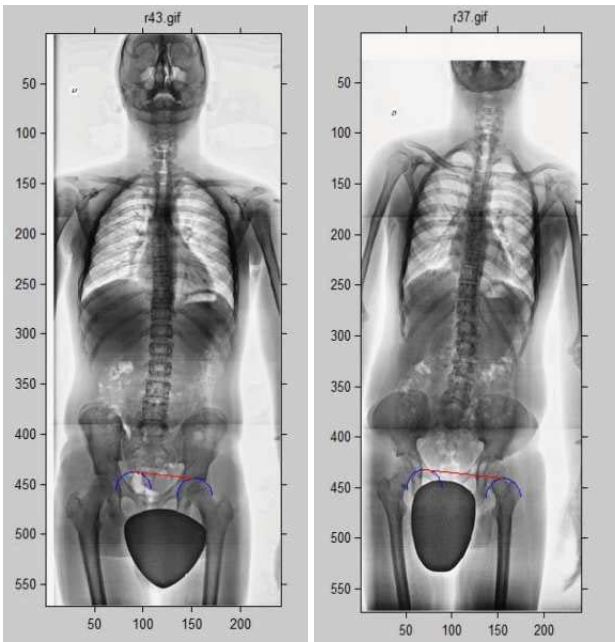


Figure 2: Some examples of the found locations of the iliac crests



(a) Only one iliac crest accurately located



(b) No iliac crest accurately located

Figure 4: Some examples which do not locate accurately the iliac crests

4 Results

In this section we discuss the results achieved by our method. We used a database with 45 X-ray images obtained from a PACS system in a local hospital. The images were in DICOM format with 5700×2400 pixels of resolution. Almost all the images were from patients suffering from scoliosis because we are focused on the study of this pathology by means of digital images. The resolution of the images was reduced to a tenth of its original one to reduce the time of processing before starting the location procedure. Experiments performed with several images suggest us that reduction in image size does not have a significant influence on the accuracy of our method.

It is important to remark that we are not interested in extract the exact shape of the iliac crest, but in the line drawn from the highest point of the left arc to the highest one of the right arc that, as we said beforehand, in an large number of cases will pass through the fourth lumbar vertebra or the interspace between the fourth and the fifth lumbar vertebrae. Therefore, accurate shape delimitation for the iliac crests is not essential.

The experiments we performed showed that in 28 out of 45 cases iliac crests were properly located, while in 3 images

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the method found the correct location for one iliac crest but failed to locate the another one. In Fig. 2 we can see some of the satisfactorily solved cases after performing the experiments. Moreover, Fig. 4 shows some cases that are not properly solved by our method.

The most important reasons that make our method fails in those cases are two: on the one hand, the presence of distortions in the area of the radiograph were the iliac crest is located, due to the position of the intestines which partially occlude it; on the other hand, the shape of some iliac crests is not completely round and this causes that our method fails because other rounder objects in the image, such as the femur heads, are located. In those cases other constraints should be included in our algorithm.

We also ran the same experiments using the method described here but using the standard HT instead of the FHT. Results obtained were satisfactory in 17 out of 45 images, whereas they were satisfactory for only one iliac crest in 14 out of 45. It is clear then that FHT can achieve better results in those images with a great presence of noise or in which the shapes sought are not clear.

5 Concluding remarks and future work

In this paper we have proposed a method for locating the iliac crests in X-ray images based on the fuzzy Hough transform. We can use the found location of the iliac crests to identify the fourth lumbar vertebra by drawing a line between the two crests and, that will be useful to initialise another algorithm designed to segment the spine. We are still working on improving accuracy and success rate of our method, as well as its efficiency, by incorporating additional constraints into the method.

It is important to remark that results achieved by means of FHT are clearly better than those obtained by standard HT. As shape of iliac crests is largely variable, it is difficult to find them by using a rigid template as HT does. For that reason FHT, which relaxes shape constraints by means of fuzzy logic, is more suitable in this problem.

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