Computer Assisted Analysis of orthopedic radiographic images

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Abstract: - Over the past few years, computers have become indispensable in many fields. This also happened in medicine, where the need for speed and precision has led to the replacement of some human activities with those, faster and more accurate, of the computers. Nevertheless, despite the accuracy and the computing power, at this moment, for superior results, there is still a need for the human presence, to supervise and interpret the results. This is why we have developed a software application that will help doctors working in a small segment of medicine: Hip Arthroplasty.

Key-Words: - Hip Arthroplasty, Canny Edge Detection, DICOM, Hough Transform, Radiographic Image Processing

1 Introduction
Medical image processing is an area of increasing interest. It includes a wide range of methods and techniques, starting with the acquisition of images using specialized devices (for example, CT devices), image enhancement and analysis, to 3D model reconstruction from 2D images. Thus, the research in this field represents a point of interest for both doctors and engineers, in their attempt to improve medical techniques, with computer assistance, in order to obtain more accurate results in treating the patients.

Among many research projects in this area of interest some of the most relevant are:
- The SCANIP [11] image processing software that provides a broad range of image visualization, processing and segmentation tools for medical purposes.
- The 3D-DOCTOR Project [12] that comes with an advanced 3d modeling software, with strong processing and measurement functions for MRI-s, CT-s, PET-s, etc.
- The Hip-OpCT software [13] that allows importing CT images in DICOM format. Once imported, the CT dataset is visualized through several modalities from which the doctors can plan the size and the position of the prosthesis.

This article describes a software application that interprets x-ray orthopedic images in order to assist doctors in hip replacement procedure. The application manages patients’ general data and x-ray images extracted from DICOM, computes parameters that are important for Arthroplasty and allows automatic or semi-automatic measurements. The second chapter of this paper describes parameters of interest for hip replacement procedure. In the third chapter we refer shortly to the data representation in the DICOM format and interpretation of the DICOM files. The fourth chapter describes the radiographic image processing we have implemented in our application, necessary to facilitate the computation of arthroplasty parameters. In the fifth chapter we present the results obtained with our application: the parameters that are automatically computed and those that can be computed with the human interaction. The sixth chapter refers briefly to the comparison between the automatic and the manual detection of the parameters important in Hip Replacement. Finally, in the last chapter, we draw some conclusions and point out the main future development directions in this domain.

2 Arthroplasty – General Presentation
Arthroplasty [10] represents a surgical procedure in which the arthritic or dysfunctional joint surface is replaced with prosthesis or by remodeling or realigning the joint. The important joint for this article is the one located at hip area. This is the reason why the article details the parameters that belong to the thigh-bone and the pelvis. Fig.1 presents the most important parameters in Hip Arthroplasty, extracted from an anterior-posterior radiography. Fig.2 presents the parameters extracted from an anterior-lateral radiography representing the hip after the insertion of the prosthesis.
For the scope of this article, three areas of the thigh-bone are analyzed: the femoral head (the nearest part to the pelvis), the femoral neck, and the femoral shaft or body (the longest part of the thigh-bone).

Fig.1. Parameters important in Hip Replacement, extracted from an anterior-posterior radiography

The parameters of interest for the Hip Replacement [7] are listed below:

1) the superior margin of the acetabulum (the superior point in which the thigh-bone meets the pelvis)
2) the inferior margin of the acetabulum (the inferior point in which the thigh-bone (the femoral head) meets the pelvis)
3) the femoral head axis or the acetabulum axis (the line determined by the two points that represent the superior margin and the inferior margin of the acetabulum)
4) the angle created by the acetabulum axis with the vertical line
5) the lesser trochanter
6) the greater trochanter
7) the tangent to the superior cortical of the femoral neck
8) the tangent to the inferior cortical of the femoral neck
9) the femoral neck axis (the axis of the cylinder determined by the tangents 7 and 8)
10) the femoral body axis or the diaphyseal axis (the axis of the cylinder that approximates the femoral body)
11) the most important parameter, extracted from the x-ray before the surgical intervention is represented by the cervico-diaphyseal angle (the angle determined by the neck axis and the diaphyseal axis). Depending on the value of this angle, it can be determined whether the patient needs or not a prosthesis. If the angle has values between 125 and 135 degrees, the thigh-bone is considered to be in normal ranges.
12) the right ischiadic tuberosity (the lowest right part of the pelvic bone)
13) the left ischiadic tuberosity (the lowest left part of the pelvic bone)
14) the ischiadic line or the horizontal reference line (the line determined by the two ischiadic tuberosities)
15) the vertical reference line
16) the line starting from the center of the lesser left trochanter, parallel to the ischiadic line
17) the line starting from the center of the right lesser trochanter, parallel to the ischiadic line; the distance between lines 16 and 17 represents the vertical distance between the two thigh-bones.

After inserting the prosthesis, some new parameters must be taken into consideration:
18) the diaphyseal axis of the femoral bone
19) the diaphyseal axis of the prosthesis or the axis of the prosthesis’ body
20) The deviation of the prosthesis (the angle determined by lines 18 and 19)

The important parameters extracted from an anterior-lateral radiography, after inserting the prosthesis, are shown in Fig.2:

Fig.2. Parameters important in Hip Replacement, extracted from an anterior-lateral radiography, after the insertion of the prosthesis

21) The axis of the prosthesis’ neck
22) The axis of the prosthesis’ body
23) The anteversion angle (the angle determined by the axes 21 and 22)

3 The DICOM Standard
In order to manage and interpret the x-rays data in a simple and organized manner, a standard for the x-ray

files is needed. This is the reason why the most popular standard for medical images was chosen: DICOM [14]. The Digital Imaging and Communications in Medicine (DICOM) standard is a detailed specification of the coding and transfer of medical images and their associated information.

3.1 Representing Data in the DICOM Format
The clinical data are represented in a variety of formats: the distances are measured in millimeters, the time in seconds, etc. The PS 3.5 part of the standard, entitled Data Structure and Their Encoding, defines 27 types of standard data, known as “value representations” (VR), that include all types of data that can appear in the medical domain. Some of the most important standard data are: Person Name (PN), Date Time (DT), and Age String (AS).

3.2 Extracting data from DICOM Files
Extracting data from a DICOM file can be made using the tags defined in the DICOM dictionary. Every tag is searched in the file, and, if found, is interpreted.

Some characteristics of the DICOM files, important when extracting data, are:
- the number of images contained in the DICOM file
- the number of bits per pixel: 8, 12, 16, 24
- the compression
- the photometric interpretation: shades of gray or color images

In case of images without compression, the extraction of the images is made pixel by pixel, according to the number of bits per pixel. For images with compression, a decompression step should be previously performed.

3.3 The Structure of the CR DICOM files
Computer radiographic images (CR) stored in DICOM files are accompanied by general identification elements and some specific information.

For example, the Patient module contains: the name of the patient, the patient’s ID, the patient’s date of birth, etc. Another module, specific for CR, CR Series, contains information about the examined body part, the view position, etc.

Our application extracts from every module the important elements for managing and interpreting the patient’s data.

4 Radiographic Image Processing
As in any image analysis application, the first step is a processing step, needed to improve the image by noise removal, contrast improvement, edges enhancement and others [4]. In our application, this step is followed by a contour extraction step, which helps in the arthroplasty parameters’ extraction.

4.1 Image Enhancement
One reason why the automatic interpretation of radiographic images doesn’t give accurate results is the fact that the radiographic images are blurred. This is why enhancing images before applying contour detection algorithms is a step that should not be omitted.

In the case of our application, the radiographic images are enhanced by the following operations:
- noise removal using Gaussian filtering.
- edge enhancement using the adaptive smoothing algorithm
- contrast improvement based on histogram equalization

4.2. Contour extraction
Most of the contour extraction algorithms which are based on edge detection follow these steps:
- detecting the edge pixels (pixels where the intensity changes abruptly)
- eliminating the edge pixels which are not also contour pixels
- connecting the contour pixels using local methods (based on the pixels’ relations to their neighbor pixels) or global methods (based on global information, for example the shape of a bone, in a computer radiography).

After trying a series of methods, the Canny algorithm [5] has been chosen in order to extract the contour lines, because this produced the best results. The result of applying the Canny detector is a binary image (Fig. 3) where white pixels represent contour pixels. Having the contour lines of the bones, the next step in our application is the extraction of the important parameters in hip arthroplasty (automatic and semiautomatic extraction).

We can observe in Fig.3 that the contour is disconnected in some parts of the radiography, and that it cannot be reconstructed with accuracy. That is why we propose to search for some salient parameters (for example the lines representing the contour of the femoral body) that can be identified without the previous reconstruction of the entire pelvic and femoral contour.
Fig.3. The image after applying the Canny Edge Detector

5 Automatic/Semi-automatic Extraction of the Hip Arthroplasty Parameters

The parameters extracted by our application are: the ischiadic line, the reference vertical line, the difference between thigh-bones, the deviation of the prosthesis, the center of the femoral head, the axis of the acetabulum (femoral head), the angle made by the axis of the acetabulum with the vertical line, the axis of the neck, the diaphyseal axis and the cervico-diaphyseal/anteversion angle.

We have reached the conclusion that the extraction of the femoral body contour should be the first step in processing the radiographic image, because it produces the most accurate results, independent of the other parameters. The contour of the femoral body can be approximated by two lines, as shown in Fig.4.

For the detection of the straight lines representing the femoral body contour, we have chosen the Hough transform. Using this technique, we have extracted all the straight lines in the image that contain a number of white pixels higher than a chosen threshold.

The output is then refined, by choosing the most appropriate lines, using the following algorithm:

- After applying the Hough transform, there will result a series of straight lines, all near the femoral body. Thus, an approximate area framing the femoral body can be determined (for example, a rectangle like the one in Fig. 4). After that, the contour will be detected by extracting the white pixels of the image, starting from the margins of the framing area towards its interior.

This algorithm generates very good results, due to the large number of pixels of the femoral body contour (the body of the thigh-bone occupies a significant area of the image) and due to the simple shape (straight line) approximating the contour.

Based on the idea of the Hough algorithm in detecting parametric curves, we have tried to determine whether some other parts of the pelvic and the femoral contour can be approximated by simple shapes like lines, circles, and/or ellipses. We have reached the conclusion that the femoral head, the ischiadic tuberosities and the lesser trochanters can be approximated by circles (Fig.5). The extraction of these parameters will be detailed in the following paragraphs.

Fig.4. Detecting the lines representing the contour of the femoral body

Fig.5. Parts of the pelvic and femoral contour that can be approximated by circles

The second parameter extracted should be the ischiadic tuberosity. The Hough algorithm for detecting circles is modified as follows:

- The centers of the circles will be searched only in the area between the two femoral bodies previous detected, down to top, ending at the first circle found.
- The circle radius is not a constant but is contained between \( r - \Delta r \) and \( r + \Delta r \), where \( \Delta r << r \)
- The algorithm takes into consideration only those pixels of the circles positioned as in Fig.6 (with \( \text{sinus} < 0.5 \)).
The algorithm for the detection of the femoral head is similar to the previous one, with the following alteration:

- The algorithm takes into consideration only those pixels of the circles positioned as in Fig. 7. (with \( \sinus > 0.5 \) or \( \sinus > -0.5 \) and \( \sinus < 0.5 \) and \( x_{\text{pixel}} > x_{\text{center}} \))

- After detecting a series of circles, with the number of white pixels greater than a threshold, the final circle will be determined as follows: \( x_{\text{center}}, y_{\text{center}}, \text{radius} \) will be calculated as the average of \( x_{\text{center}}, y_{\text{center}} \), respectively \( \text{radius} \) of all the found circles.

The detection of the lesser trochanter is similar to the one of the femoral head, with the modification that only the white circle pixels positioned as in Fig. 8 (with \( x_{\text{pixel}} > x_{\text{center}} \)) will be taken into consideration.

After detecting the contour of the femoral body, the ischiadic tuberosities, the femoral head, and the lesser trochanter, all the other parameters can be determined automatically.

The ischiadic line is extracted as follows: The ischiadic line represents the line connecting the two lowest points of the circles approximating the ischiadic tuberosities.

The reference vertical line is determined in an automatic manner based on the ischiadic line. It is the line perpendicular to the ischiadic line, in its middle.

The vertical distance between the two thigh-bones depends on the ischiadic line, the vertical line, and the two lesser trochanters. The application will draw the lines that start from the centers of the circles representing the two lesser trochanters, and are parallel to the ischiadic line. The vertical distance between the two thigh-bones is computed as the length of the segment that connects the intersection points of the reference vertical line with the two parallel lines previously determined.

The diaphyseal axis depends on the two lines that represent the contour of the femoral body. The body of the thigh-bone can be approximated by a cylinder. The axis of this cylinder is the diaphyseal axis. The axis of the prosthesis’ body will be determined similar as the femoral diaphyseal axis.

The deviation of the prosthesis can be extracted automatically and depends on the axes of the femoral body and of the prosthesis’ body.

The acetabulum axis (the femoral head axis) is determined automatically, after extracting the center of the femoral head. The application identifies, on the femoral neck, points belonging to the inferior and superior parts of the neck contour, and then follows the two contour lines of the neck until they meet the pelvis. The two points where the neck’s contour meets the pelvis represent the superior margin and the inferior margin of the acetabulum. After determining these two points, the acetabulum axis can be drawn.

The angle made by the acetabulum axis with the vertical line is determined automatically, after extracting the axis of the femoral head and the reference vertical line.

The axis of the femoral neck is determined automatically, using the center of the femoral head. Similar to the extraction of the information regarding the acetabulum axis, after positioning and delimiting the circle that represents the femoral head, two points on the neck contour can be identified. And then, the entire contour of the neck can be determined. Two tangents are drawn to the neck contour at the points (one on the convex curve and the other on the concave curve of the contour neck) located at the closest distance. The perpendicular bisector of the segment determined by these two points represents the axis of the femoral neck.
The cervico-diaphyseal/anteversion angle is determined automatically, using the femoral neck axis and the diaphyseal axis.

The application is considered semiautomatic because of the possibility for the human intervention, in case the application cannot automatically identify some parameters or does not identify them correctly.

6 Experimental results
The data sets provided by the “Floreasca” Emergency Hospital have been processed both manually and in automatic manner.

The conclusions are:
- The automatic detection of the lines representing femoral body contour and the automatic detection of the ischiadic tuberosities are as accurate as the manual detections
- The automatic extraction of the circle representing the femoral head is approximately 85% accurate, compared to the manual one.
- The algorithm for detecting the circle that represents the lesser trochanter does not generate very good results (50% accurate, compared to the manual detection), because of the small number of pixels representing the lesser trochanter (the lesser trochanter occupies only a small area of the radiographic image)
- The other parameters depend on the previous parameters, therefore the accuracy of the automatic detection of these parameters depends on the accuracy of the femoral body contour, the ischiadic tuberosities, the femoral head and the lesser trochanter automatic extraction.
- The automatic extraction is a lot faster than the manual one. If the automatic image processing takes several seconds, the manual detection of all the parameters could last over 20 minutes.

7 Conclusions and further research
The research in the field of medical image analysis is a continuous challenge. The need to discover new image analysis algorithms and new automatic learning techniques that would help in computer assisted diagnosis is and will be a topic of interest for researchers.

The results of our research, presented in this paper, prove that solutions do exist. Although not all the arthroplasty parameters determined automatically were 100% accurate, the application proved to be very useful to doctors. And last but not least, the application allows patients’ data saving and management, during a long period of time after the hip replacement procedure.

Our future research direction in the field of computer assisted hip arthroplasty is to make automatic measurements on the femoral bone 3D model, reconstructed from CT/MRI images.

References:
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