

# Semi-automatic Detection of Corticalis Borders in Two-dimensional Radiographies to Improve Pre-operative Planning

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**Abstract.** This paper suggests an algorithm to detect corticalis borders in a radiograph. It is robust against occurring interferences in radiographies, because it is a global working procedure. This segmentation is part of semi-automatic assistant functions, which are developed to support surgical interventions. The algorithm will be introduced related to the calculation of the femoral CCD-Angle. Further subjects of the presented proposal cover special aspects when using a two-dimensional radiography for pre-operative planning instead of CT or MRT scans.

## 1 Introduction

The work outlined in this paper is embedded in the development of the modiCAS assistant system. modiCAS is the abbreviation for modular interactive computer assisted surgery. It is a system to support the surgeon during surgical interventions. This paper describes the determination of important surgical parameters which may later be used during the intervention supported by navigation systems or a robot based assistant system.

Radiography is the most used modality in orthopaedics and trauma surgery. The challenge consists in extracting as many parameters as possible out of radiographies during the planning phase to allow an optimal prearrangement of the intervention. An additional problem is the scaling of radiographies. In contrast to the scaling of CT or MRT scans, projection images of two-dimensional x-ray scanners do not contain inherent scaling information.

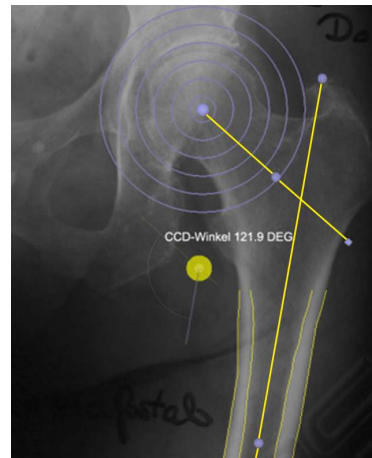
Due to the intraoperative use of c-arms, radiographies are also generated during the intervention. So it is possible to extract parameters to control a mechatronical assistant system. For this task the scaling of radiographies is very important.

Thus there are several applications where the accurate and easy extraction of important parameters for a surgical intervention is of high relevance. In order to support the user here, we develop semi-automatic assistant functions within the modiCAS project.

A semi-automatic assistant function is a combination of automatic functions and manual steps. All parameters which are computed automatically by an algorithm will be transferred to a planning object. These planning objects allow the user interaction,



**Fig. 1.** Screenshot of a hip replacement planning with modiCAS-Planning.



**Fig. 2.** Femur and neck axis to measure the CCD-angle.

and the user has the chance to manipulate the parameter before he starts the next step of the semi-automatic assistant function.

One advantage of such an assistant function compared to the manual creation of planning objects is the advantage in time. Even in the case of planning standard interventions like hip replacements, time requirements play an essential part for the acceptability of such a planning tool.

This paper suggests a procedure to allow the fast and safe segmentation of long bone corticalis borders in radiographies. This procedure is the base of a semi-automatic assistant function to determine the CCD-angle of a femur bone. In a further step this assistant function will make a proposal for the optimal femoral implant out of a database.

## 2 Problem

Hip replacement procedures require the pre-operative planning of a pelvic and a femoral component. For each component an appropriate size and type must be selected out of a database. In the next step this component must be placed in the image data. Figure 1 shows a screen shot with a complete planning and three-dimensional implant models. This planning is carried out using the software modiCAS-Planning.

The presented semi-automatic assistant function supports the surgeon during the planning of the femoral shaft component. Some patient specific parameters must be determined out of a radiograph to select a fitting shaft implant.

Figure 2 shows the femoral axis and the neck axis which are two of these parameters. The angle between these axes is the CCD-angle. Apart from the size the CCD-angle is an important criterion to select the shaft implant. Implant manufactures offer shaft implants with different CCD-angles in adaptation to the varying anatomy of different patients.

It is possible to compute the femoral axis out of the corticalis borders with a smoothing function. The shown rotation center of the head is one point of the neck axis. In addition to the CCD-angle the corticalis borders and the rotation center of the head are other criteria which are important during the implant selection.

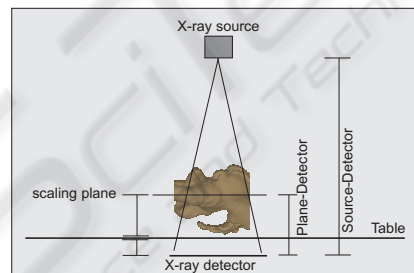
The proposed procedure to determine the corticalis borders should be released within the existing surgical tool modiCAS-Planning. The functionality will be explained at the femoral bone. The aim is to support the user during the implant selection and positioning of a shaft.

### 3 Specific Aspects using Radiographies

If radiographies are used for planning, it will be important to take some specific aspects in consideration. In this paper two aspects are discussed. The first aspect is the scaling of radiographies. The second aspect is the reconstruction of three-dimensional information out of a series of two-dimensional radiographies.

#### 3.1 Scaling of Radiographies

As known radiography is a projection bases technology. Depending on the arrangement (Figure 3) of x-ray source, x-ray detector and patient the recorded image appears greater by a certain image scaling factor (1). For measurement of length in radiographies the scaling factor must be known, but it is a problem to determine the correct one.



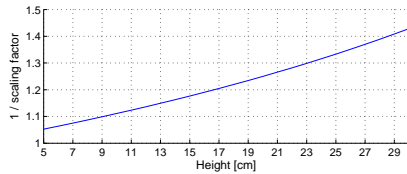
**Fig. 3.** Assembly of an X-ray equipment for radiography.

The scaling factor (1) describes the size difference between a pixel on the detector and the imagined region in the patient.

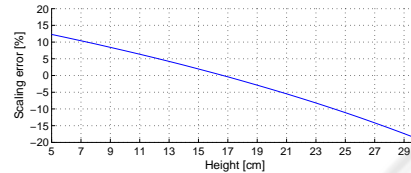
$$F_{scale} = \frac{S_{SourceToDetector}}{S_{SourceToPlane}} \quad (1)$$

In this equation  $S_{SourceToDetector}$  is the distance between the focus of the x-ray source and the x-ray detector. The value of  $S_{SourceToPlane}$  is the distance between the focus and a plane through the patient which is parallel to the x-ray detector. The height of this scaling plane above the detector depends on the one hand on the use case and on the

other hand on the individual anatomy of the patient. These two dependences will be not reflected, if a standard scaling factor is used. The dependency between scaling factor and scaling plane is shown in Figure 4.



**Fig. 4.** Scaling factor depending on the height of the scaling plane. The distance between focus and detector is 100 cm.



**Fig. 5.** Percental scaling error by using a standard scaling factor of 1:1.2 depending on the height of the scaling plane.

In equation (2) the scaling factor depends on the distance  $h$  between the x-ray detector and the scaling plane through the patient.

$$F_{scale} = \frac{S_{SourceToDetector}}{S_{SourceToDetector} - h} \quad (2)$$

Figure 5 shows the percentage error which will occur, if a standard scaling factor of 1:1.2 is used instead of the correct scaling factor. The graph illustrates the scaling error of round about one percent for every centimetre change in altitude.

There are the following consequences relating to the selection of a cup implant. Usually cup implants are available in size steps of 2 mm. The percentage difference between a cup with a diameter of 56 mm and one with 58 mm is round about 3.5% for example. So it is possible to plan a cup that differs in one or two size steps to the cup which is needed.

It is clear that the standard scaling factor, which is often used in DICOM files, allows no exact measurements. Another area where such standard scaling factors are applied, are two-dimensional implant templates. These templates are used to make a manual planning on not scaled radiographies by using a light box.

One possible solution to reduce this problem is a scaling body with a known size. This scaling body must be placed in the radiography on the height of the required scaling plane. At the beginning of a new planning the size of this scaling body can be measured in the image to get the scaling factor. The accuracy of a scaling factor which is determined in that way depends on the error which is made by placing the calibration body on the required height. If only angles like the CCD-Angle should to be measured in a radiograph, a scaling will be not necessary.

### 3.2 2D-3D Reconstruction

If there is a set of radiographies available during the planning time, it will be possible to extract some three-dimensional information out of these images. Therefore it is required, that the recording situation of each image is known.

There are some algorithms for this kind of three-dimensional reconstruction suggested in the literature. The procedure described in [1] is qualified for pre-operative planning. It bases on a special calibration body which must be placed in the image during the recording time. So it is possible to reconstruct the recording situation during the planning and pose the images in the virtual planning space.

A navigated c-arm is another possibility to get radiographies with a known recording situation. With this technology the recording situation is delivered directly by the c-arm and no complex algorithms are used by the reconstruction.

Semi-automatic assistant functions would be appropriate to generate three-dimensional information out of such arranged radiographies during the intervention in a short time.

## 4 Known Procedures for Corticalis Detection

Several procedures have been developed in the last years to detect the femoral contour, but most of these proposals were limited to the outer femoral contour. Some of the procedures are based on a two-dimensional femur model, which is registered atlas based in the first step. In the second step a fitting procedure deforms the two-dimensional model to the real contours in the x-ray. The active contour algorithm is one option to fit the model. [4], [6].

Another possibility is the deformation of a three-dimensional statistical model as described in [5]. This approach needs more than one radiograph. In addition the orientation between the radiographies is required. This work makes a proposal of a procedure that detects the inner and outer contour of a corticalis in a fast and stable way.

## 5 New Procedure to Detect Corticalis Borders

Radiographies often have interferences like shades, channels or local overlapping. Due to this it is complicate to get good and save results with procedures which have a local operation method like the path finding algorithm. Another problem which must be solved to use a path finding algorithm is the detection of the starting points. The new proposal of this paper has a global operation method. Due to this it has the advantage to be more robust against local interferences.

The procedure of this proposal is divided in several steps. Within these steps some standard methods out of the image processing are used. The general functionality is as follows. At first as many as possible groups composed of 4 points were build. Each of these points should be a part of the corticalis borders. The following steps process some plausibility tests to filter out point groups that don't completely belong to the corticalis borders.

### 5.1 Compute Gradients

The first step computes the gradient in x-direction. This is done by a Sobel operator (3) from [2]. The advantage of this operator is its small angle error. Further the gradient image will be normalized.

$$H_x^{S'} = \begin{bmatrix} 3 & 0 & -3 \\ 10 & 0 & -10 \\ 3 & 0 & -3 \end{bmatrix} \quad (3)$$

## 5.2 Quadruple Building

In this step the gradient image of the previous step will be processed line by line. If the application requires only some interpolation points of the corticalis borders, it will be possible to process only each n-th line of the image. The size of n depends on the required distance between the interpolation points.

The criteria which are used to decide whether an image point belongs to the searched contour or not are derived from the following considerations.

The gradient through a bone in x-direction has a typical history shown in Figure 6. The recognizable minima and maxima of the inner and outer corticalis borders are named with  $x_1 \dots x_4$ . Such a group of four points will be named as a quadruple in the following text. In a quadruple  $x_1$  and  $x_3$  represents minima,  $x_2$  and  $x_4$  represents maxima. A further condition for a quadruple is that the Points  $x_1 \dots x_4$  are in rising x-direction. There are some advantages caused by the combination of four points to a quadruple:

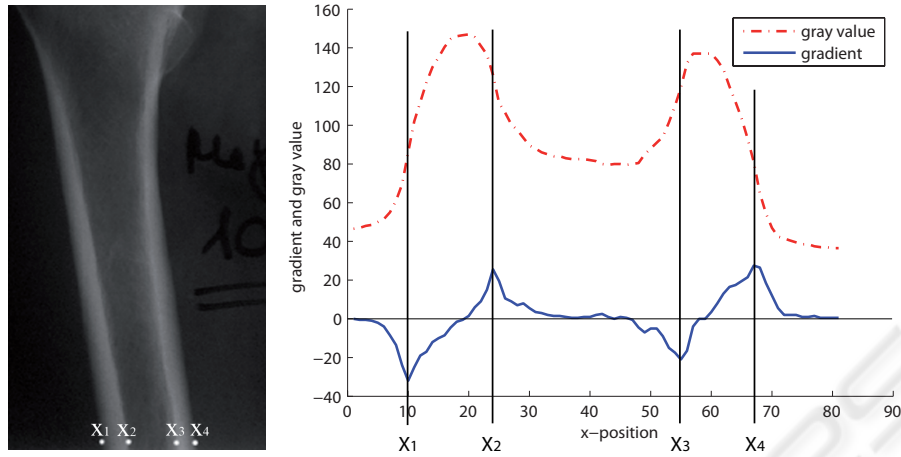
- It is possible to define requirements, which must be fulfilled by each quadruple.
- It is possible to compute the center point of each quadruple. The center points of one femur must be up to a line approximately.
- In the end it will be sure that there is the same number of points on both femoral sides. Due to this it will be simplified to compute the center axis of the bone with a linear smoothing function.

The algorithm creates two lists, to identify all possible quadruples of the current image row. The first list stores all positions of the row where the gradient reaches a local maximum. The second list stores all positions of local minima. Thereto the algorithm runs through the current image row and detects minima and maxima in an alternating way. A new extrema will be found, if the magnitude decreases in the following at least 80% or brakes through the zero line.

After detecting all extreme positions of the current image row only the extreme positions with the biggest magnitude of the gradient will be used furthermore, to suppress noise and other interferences. A pelvic overview with two femora contains 4 maxima and 4 minima which are interesting. By disturbance or other objects like radiation protectors there could be other vertical edges which produce extreme positions in the horizontal gradient. These extrema could have a higher magnitude than the searched extreme positions. Based on the experience of our tests a maximum number of 15 minima and 15 maxima are adequate to be sure that the searched extreme positions are included.

After this the algorithm builds all possible quadruples out of the maximal 30 local extrema. Each of these combinations will be tested with several criteria. If a quadruple passes all tests, it will be saved as a candidate of the current image row for further processing steps.





**Fig. 6.** Gray value and gradient in x-direction through a femur with the extreme positions  $x_1 \cdots x_4$ .

These tests analyze several characteristics of the gradient at the positions  $x_1 \cdots x_4$  and can be divided in two groups. The first group is responsible for the magnitude of the gradient in the extreme positions. The second group checks the geometrical characteristics.

The following rules represent the conditions of the gradients magnitude.

$$|2 \cdot \text{grad}(x_1)| > |\text{grad}(x_2)| \quad (4)$$

$$|2 \cdot \text{grad}(x_4)| > |\text{grad}(x_3)| \quad (5)$$

$$||\text{grad}(x_1)| - |\text{grad}(x_4)|| < \frac{1}{2} \quad (6)$$

$$||\text{grad}(x_2)| - |\text{grad}(x_3)|| < \frac{1}{2} \quad (7)$$

The inequality (4) is based on the observation that the minimum at position  $x_1$  is usually bigger than the maximum at position  $x_2$ . The rule (5) follows analogous to that for the positions  $x_3$  and  $x_4$ . The rules (6) and (7) are the results of the fact that the magnitude of the extremums at  $x_1$  and  $x_4$  respectively  $x_2$  and  $x_3$  are round about the same size.

The following substitutions are introduced for better expression of the geometrical rules.

$$w_{CR} = x_2 - x_1 \quad (8)$$

$$w_{CL} = x_4 - x_3 \quad (9)$$

$$d_1 = x_4 - x_1 \quad (10)$$

$$d_2 = x_3 - x_2 \quad (11)$$

$w_{CL}$  and  $w_{CR}$  are the latitudes of the left respectively right corticalis. The outer and inner diameter of the bone is described with  $d_1$  and  $d_2$ .

The latitudes of the left and right corticalis usually do not vary more than a factor of two. This is the reason of inequality (12). The proportions between the left and right corticalis on the one hand and the inner and outer diameter on the other hand are formulated with the rules (13, 14, 15, 16). The acceptable ratio between inner and outer diameter is formulated with rule (17). The factors which are used in these rules are selected in a way that no quadruple of the test data will fail a test, if it is completely up to the femoral corticalis borders.

$$\frac{1}{2}w_{CR} < w_{CL} < 2 \cdot w_{CR} \quad (12)$$

$$0.5 \cdot w_{CL} < d_2 < 5 \cdot w_{CL} \quad (13)$$

$$0.5 \cdot w_{CR} < d_2 < 5 \cdot w_{CR} \quad (14)$$

$$8 \cdot w_{CL} > d_1 \quad (15)$$

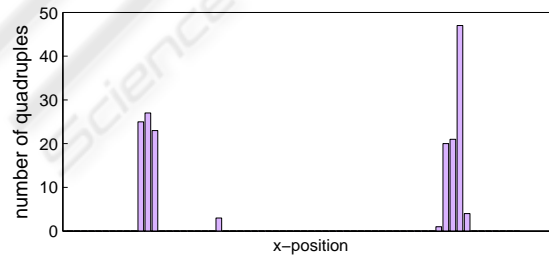
$$8 \cdot w_{CR} > d_1 \quad (16)$$

$$4.2 \cdot d_2 > d_1 > 1.2 \cdot d_2 \quad (17)$$

### 5.3 Localise the Femora

In this step the algorithm detects the number of bones and the detected quadruples will be attached to the different bones. In the case of femur detection there can be an image with one or two femora.

Therefore the x-axis will be divided into three parts of equal length, and the centre point as the arithmetic average of the four points will be computed for each quadruple. On basis of the centre point position the algorithm allocates each quadruple to one of the three segments. When all quadruples are attached to a segment the number of quadruples per segment can be compared (Figure 7).



**Fig. 7.** Distribution of the centre points over the x-axis in the case of a pelvic overview.

If the left and the right segment have more quadruples than the inner segment, the image is a pelvic overview with two femora. In this case the quadruples which are



attached to the inner segment will be deleted and the quadruple attached to the outer segments will be attached to two femoral objects. In the other case only one femur is visible in the image and the algorithm use the quadruples of the inner segment to build one femoral object

#### **5.4 Filtering with the Hough Transformation**

This step will be passing through for each detected femur. It computes a first estimation of the center axis of the quadruples which are attached to a femur.

At this time the algorithm assumes that most of the points which are attached to a femur are up to the corticalis contour. Due to this there will be a clearly straight, if the center points of each quadruple that is attached to a femur will be painted in an image. Although there may be some quadruples with center points more or less far away from this axis. This points can be called as noise.

For estimation of the center axis a procedure is needed that is robust against these outliers. The Hough transformation for line detection is one candidate. The result of the Hough transformation is only influenced by the points which are part of the line. All other points have no influence to the result as long as there is no accumulator filed with more points than the accumulator field of the searched straight. Alternatively we have made some trails with a smoothing function. But at this processing time there can be too much center points far away from the bone axis. These points would have a big influence to the results of such a smoothing function particularly combined with short bone segments. In this case there will be only a low number of image rows and the influence of such outlier increases.

However, the Hough transformation has a further big advantage, because it is very simple to shrink the allowed range of angles. If images with perpendicular aligned bones like femora are processed, the asked straight will be as well more or less perpendicular aligned.

The distance between the center point and the estimated bone axis is the criterion for filtering in this step. To define a limit for this distance the standard derivation of the distance of all center points will be computed. Afterwards all quadruples with a greater distance between their center point and the estimated axis than the calculated standard derivation will be filtered out.

#### **5.5 Final Filtering**

The last step is the filtering procedure with a smoothing function. Thereto the algorithm computes a best-fit line with a smoothing function based on the method of smallest square deviation.

If there are more than one quadruple per image row and femur, the quadruple with the closest center point will be selected. All other quadruples will be filtered out and a recalculation of the best-fit line starts.

The final best-fit line is the center axis of the bone.

## 6 Realization within the Modicas Software Framework

The suggested procedure was realized as plug-in of the surgical planning software modiCAS-Planning which is a part of the modiCAS-Project. This project realizes the complete chain of a surgical intervention.

Therefore it is possible to create a planning based on two- or three-dimensional modalities. Afterwards the surgeon can be supported during the intervention by a mechanical assistant system.

The planning software is designed as a framework. Further it has a plug-in interface to allow simple appending of new functions to the system. Additionally the software has an own scripting language to bind the operations of a planning or an intervention in a workflow. The advantage of this workflow concept is the easy and fast method of interaction. The user will be guided step by step and there is no need to select the next function manually. To support the new functions of the plug-ins in a workflow, it is although possible to extend the scripting language via plug-ins.

The plug-in which was developed to demonstrate the procedure is able to create line planning-objects for the femoral axis and contour planning-objects for the corticalis borders, which can be used for further planning steps.

A second plug-in was realized for semi-automatic scaling of radiographies. This plug-in detects a round calibration body with the procedure suggested in [3]. The suggested algorithm bases on the detection of vectors with opposite directions. If a calibration body is found, the plug-in creates a circle planning object which will be modified by the user, if there is any need. After confirmation by the user the image will be scaled to the correct size.

## 7 Discussion

The procedure was validated with twenty radiographies from five different X-ray equipments for radiography. These images contain 29 femora which should be detected. The results have been compared to manual created femoral axis.

It is enough to get some base points of the corticalis borders to compute the femur axis. The pixel distance between these points depends on the image resolution and the expected size of the bone. During this validation, the algorithm worked on each 10th image row. The reason for this is the decreasing computing time which is important in a semi-automatic assistant function to produce no time of waiting for the user.

It was possible to detect whether the image was a pelvic overview with two femora or a single sided radiography. There was only one image with a detected quadruple which doesn't belong to a femur. Figure 8 shows the result of one of the images.

In the upper part of the femur, where the corticalis becomes smaller, not all quadruples were found, but this makes no big difference concerning the calculation of the femoral axis.

The detection of the outer corticalis contour was robust. On the inner side there are 5 of 29 femora with inaccuracies in one or two of the detected quadruples. In all of these cases an inner contour point is moved too much in the direction of the femoral center axis (Figure 9). Due to the low number of faulty points this has no consequence

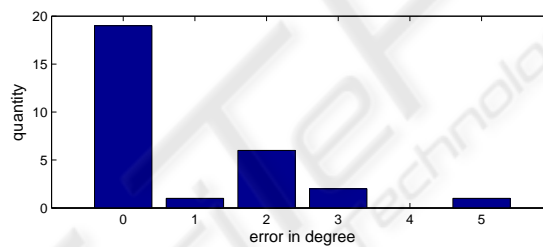


**Fig. 8.** Detected quadruples and femur axis within the original radiography.



**Fig. 9.** Faulty pixel of the inner femoral corticalis border.

to the detection of the femoral axis. It should be able to resolve this problem by a post processing of the contour points.



**Fig. 10.** Results of the validation. 28 of 29 femora were detected in 20 radiographies.

Figure 10 shows the differences between the detected femoral axes compared to the manual created axes. In 19 of 28 cases there were no error. One femur could not be found.

Also radiographies of patients who already had one or two implants were tested. In these images it was possible to detect the corticalis only below the implant.

The presented algorithm needs a vertical aligned long bone. In the tested images the femora were rotated  $13^\circ$  at maximum. In this range of rotation no degeneration of the results could be observed. If it is known that the long bone is horizontal aligned, it will be possible to rotate the image or to use image cols instead of image rows during the computation.

Due to these results the suggested procedure to detect long bone corticalis borders is stable and accurate enough to use it in combination with the semi-automatic assistant function described in this paper. Similarly the computing time round about 4 seconds on a standard computer is short enough.

**Table 1.** Differences between manual and automatic detected femoral axes.

	Results
minimal derivation	0°
maximal derivation	5°
standard derivation	1,53°
not founded femora	1

In the next time we will validate the procedure with an expanded amount of images. Additionally we plan to test the algorithm with other types of bones.

## 8 Conclusions

This contribution explained a procedure to detect the corticalis borders of a long bone. The procedure was classified by describing the use cases and alternative procedures.

The stable and accurate detection of the femoral axis and the femoral corticalis borders and their use in a semi-automatic assistant function was the reason to develop the presented procedure.

The suggested procedure was realized as a plug-in for the surgical planning tool modiCAS-Planning. First steps of the validation were auspicious.

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