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Use of Fourier domain filtering and dynamic programming in finding a titanium coil implant in high voltage x-ray images.

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ABSTRACT

This paper deals with the problem of finding precise position and orientation of a titanium coil implant in humans. Analysis of high voltage X-rays stereo images are used to determine the true 3D position. High voltage images inherently presents with poor contrast. Various image processing techniques, such as template matching and grey scale morphology operations were tested. A final solution based on filtering in Fourier domain, greyscale morphology and a new shortest path algorithm is implemented as a set of ImageJ macros. The method has been tested on 100 images. The method correctly determined the position of the titanium wire within less than 1 mm of ground truth determined from manual analysis of the images.

Keywords: ImageJ, Fourier domain filtering, Grayscale morphology, shortest path algortm.

1. INTRODUCTION

This paper presents a technique to detect a titanium coil implant in humans. The implant is a 0.5-0.7 mm thick titanium wire coiled into a diameter of 8 mm and a length of 20-50 mm Figure 1. High voltage x-rays are used to image the individual humans. Each image thus contains a 2D projection of the implant. A material of one hundred images was used for the analysis. The work in this paper assumes that the implant can be translated and rotated in 3D, but always as a rigid object. The goal was to develop an automatic algorithm with a high success rate for detection, with good accuracy.

Figure 1. The stent made of a titanium coil

The images are generated by using High voltage x-ray. High voltage x-ray images have a poor contrast compared to conventional x-ray images. This is due to the fact that the dominating physical interaction process in high voltage is Compton scattering, where the scattering probability varies with electron density of the scattering material. So the poor contrast in high voltage x-ray images is due to the fact that electron density varies relatively little between solid matters. The maximal attenuation and thus contrast of the implant is where the radiation path through the titanium material are greatest. This happens were the radiation is tangential to the inner diameter of the coil, which is sufficient for the implant to be clearly visual to the human eye in all the images. See Figure 2. But the attenuation in the titanium will not be different from attenuation in bone or other in homogeneities in the human body.

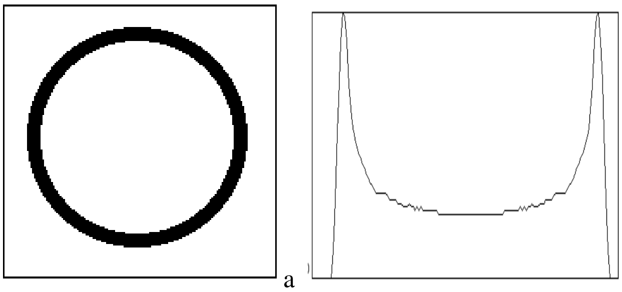
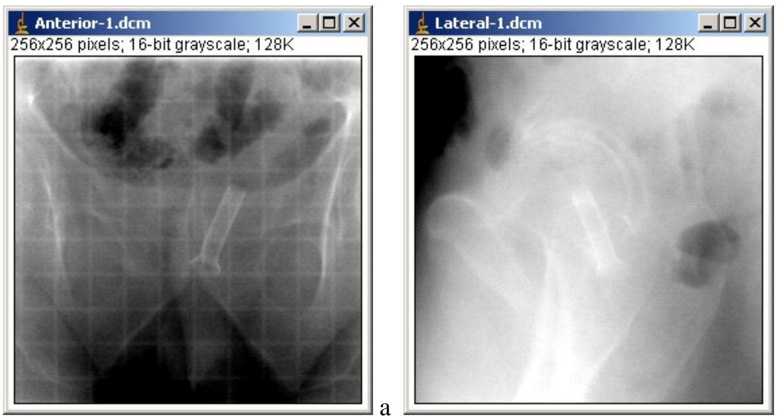

a b

Figure 2. a: cross section of the implant. b: The expected profile of x-rays through the cross section of the implant.

2. MATERIAL AND METHOD

Immediately before the treatment of the patient two orthogonal images are taken, and the goal is to estimate position and orientation of the implant from these images. Several different approaches have been attempted for an automatic detection of the implant. The implant is depicted as parallel lines or curves in the image, thus an initial attempt was to use various line filters in order to enhance the implant. The thickness of the titanium wire presented on the images is typically 1-2 pixels wide. Thus a line filter was used. Line filtering however was not sufficient to automatically identify the implant in all cases. This was due to the poor contrast and the fact, that line filtering enhance noise and bone structures as well at the signal from the implant.



a b

Figure 3 a: Anterior image with implant and grid from the bearing. b: Lateral image with implant and lots of similar structures from the bones.

3. METHOD

Template matching on the line filtered images was then attempted. The well defined geometry of the implant in principle makes it suitable for template matching. Because of a strong orientation in the template, the method requires exactly equal orientation of both the template and the image, for the match to succeed. Orientation of the line filtered image was obtained using a Fourier transformation and radial summation to obtain the most pronounced orientation in the image. Again the enhanced noise degrades the possibility to orientate the image correctly to the template, and consequently template matching had a low success rate. Furthermore in cases with a curved implant, rotations in 3D may change the shape of 2D projection to a degree where it differs from the template, which in turn will reduce the accuracy of template matching.

To further exploit the fixed geometry of the implant, especially the fact that the titanium coil is imaged as a set of parallel lines, see Figure 3, morphological operators were implemented. Grayscale morphology was used to erode pixels with a horizontal distance different from the fixed geometry of the coil. The morphological operation was succeeded by a binary threshold of the image and analysing the image in 8-connectivity particles. The implant was then extracted as the largest particle in the binary image. This method showed to be quite successful in analysing images with a straight implant. The method although had an inherent reduced accuracy because noise tended to fragment the implant and minor parts of the implant could be lost, even though this could be counteracted using a binary closing operation in the vertical direction along the stent.

Final approach.

On the anterior image a grid pattern is visible. This is the grid from the bearing frame supporting the patient. This pattern is strictly parallel to the image orientation and thus it can be removed using ImageJ's Fourier Bandpass Filter, which has build in methods for removing vertical and horizontal structures in images. This is the command from ImageJ's recorder.
run("Bandpass Filter...", "filter_large=1000 filter_small=0 suppress=Vertical tolerance=5 display");
The parameter *display* gives us an image of the filter function in the Fourier domain. In the same way a filter for removing the horizontal lines are build. By multiplying these two filters a new filter for removal of both directions, in one operation, is easily made.

To enhance vertical lines, a convolution filter, with this kernel has proven to quit efficient.

-1	0	2	0	-1
-2	0	4	0	-2
-4	0	8	0	-4
-2	0	4	0	-2
-1	0	2	0	-1

It is the second derivative in horizontal direction and approximated Gaussian blur in vertical direction[1]. However the orientation of the target is not always vertical, the angel varies up to +- 45º, but it is known from a previous CT-scan of the patient. Thus the line filter needs to be rotated to the desired direction. To make such a filter, it is required to rotate the kernel before doing the Fourier transformation. This is easily made by first generating a new 32-bit black image of the desired size with 1 arbitrary pixel set to the value 1. The result of convolving with the desired kernel gives us the filters impulse response; this is then rotated the desired angle with interpolation, and finally after Fourier transform we have a filter function, which can be multiplied with the previous generated horizontal and vertical filter. Figure 4 shows the filter in Fourier domain. It is made by multiplying ImageJ's build in horizontal and vertical filter with the Fourier transform of the kernel rotated 30º. The black cross is responsible for removal of the parallel grid lines.

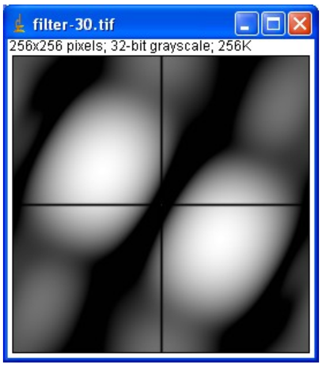


Figure 4. A filter function for enhancement of lines in 30º direction the black lines are responsible for removal of both horizontal and vertical lines at the same time.

The result of using this filter as FFT Custom filter in ImageJ on the image in shown in Figure 3a is seen in Figure 5a.

An important feature of the implant is that the width is 8mm and thickness of the thread is 0.65mm in this application. This means that the distance between the two visible lines is 6.7 mm. The distance from x-ray source to centre of patient and from x-ray source to the imaging device are recorded in the Dicom header, and extracted with the plugin "Query Dicom Header". Together with pixel size of the imager (0.78mm/pixel) it is now possible to calculate the size of a pixel. Normally the pixel size is between 0.4 and 0.6 mm/pixel. Finding the target by thresholding in Figure 5a is still impossible. From the previous CT-scan the expected orientation (α) is known; so greyscale erosion [1,2,3] width a 2-point horizontal structuring element with a point distance equal to 6.7/(pixelsize * cos(α)) will remove almost any bright pixel, except where we have two bright pixels at the specified distance. The erosion is made by using the plugin Gray_Morphology contributed by Dimiter Prodanov. The result is seen in Figure 5b. Finding the target by thresholding in this image is much better, but still not robust enough.

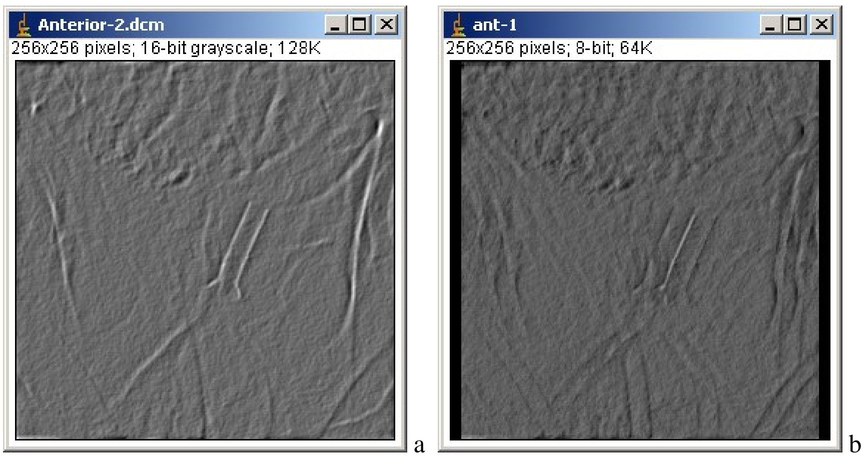


Figure 5. a: result of using the filter in figure 4 as custom filter on the image in figure 3a. b: The result after grayscale morphological erosion with 2 point horizontal structuring element.

Dynamic programming or shortest path as defined by Dijkstra's algorithm might solve the problem. We define a simplified version of Dijkstra's algorithm where we try to find the shortest path from top to bottom of the image. First a cost image, with initial values from the eroded image (Figure 5), is build. In this the following cost function is applied to all pixels except the top line:

$$c(x,y) = c(x,y) + max(c(x-1 ,y-1), c(x ,y-1), c(x+1,y-1))$$

Then backtracking from highest value in lower line back to the top line by always following the max value of the three pixels above is performed. The cost function image is seen in *Figure 6*. The optimal path through Figure 5b is shown superimposed on the image before erosion on Figure 7. Here it is visualized that the path goes right through the middle of the implant. The pixel values from which the path is build is shown in Figure 8. Smoothing this curve by a Gaussian follow by differentiation has a maximum at the top of the implant and a minimum at the bottom of the implant. The part of the path between these two points together with marking of the two points is seen superimposed on the original anterior and lateral image in Figur 9.

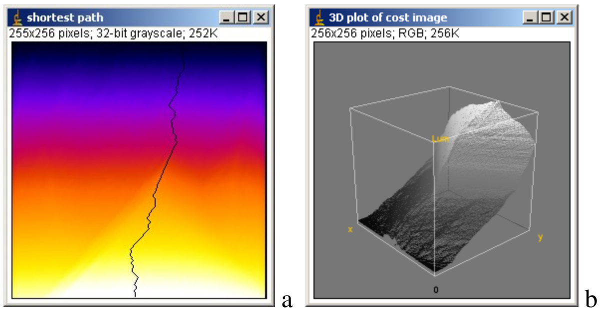


Figure 6. a: the cost image with optimal path shown in black. b: 3D-wiev of figure 3a made by the plugin Surface Plot 3D.

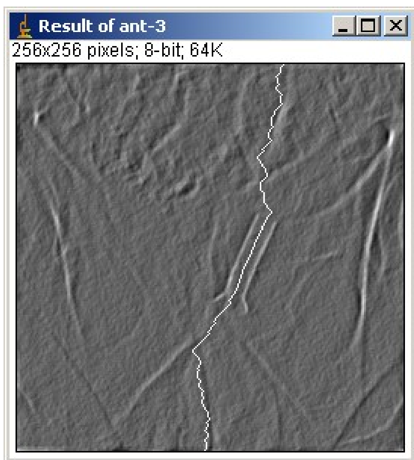


Figure 7. Optimal path superimposed on figure 5a.

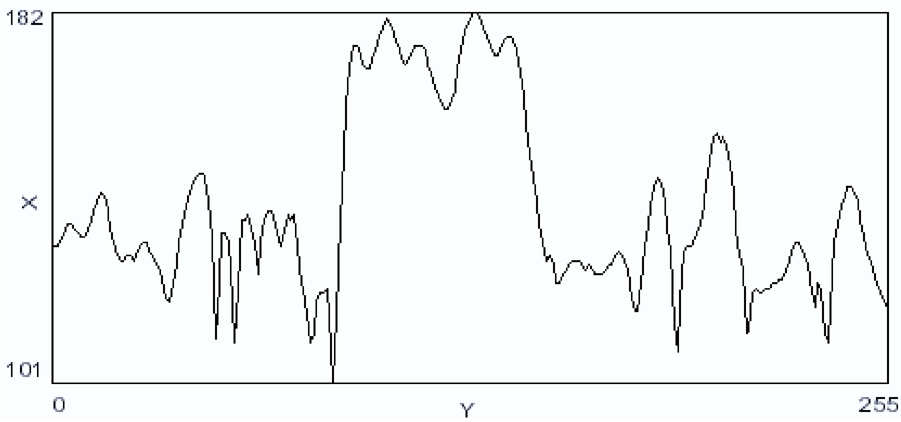
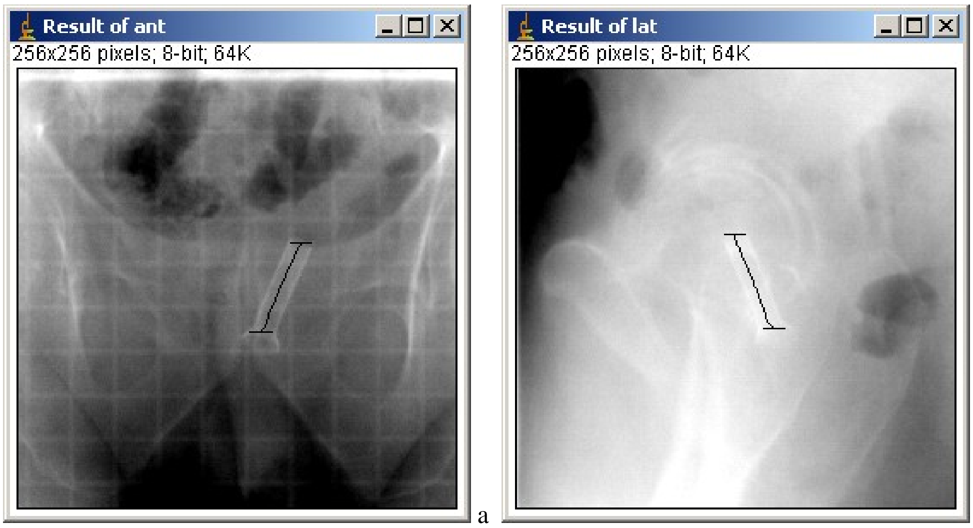


Figure 8. Plot of data along the optimal part through figure 5b.

Results.

The method has been tested on 100 images from 7 patients, and it was found, that the optimal path through the eroded image always follow the expected middle line through the implant, but in some cases top and button point from the differentiation are misplaced. By not using direct neighbours in the differentiation, but values 5 pixels apart, the top point is found in all images. In some cases it was still impossible to find the bottom point. In these cases the bottom point was defined from the top point + the length of the implant, which we know from previous CT-scanning. Visual inspection of the results reveals that the found centre point is correct in the x direction and the error is less than 2 pixels (app. 1mm) in the y direction.



Figur 9. Marking of optimal path and top and bottom point on anterior (a) and lateral (b) image.

Discussion.

The goal of this work was to find a method for finding position and orientation of a titanium implant from high voltage x-ray images. It is shown, that it is possible to remove the periodic grid pattern from the anterior images completely. The two parallel lines from the implant are enhanced by line filtering. Especially in the lateral images it is difficult to see the implant because of many similar structures from the bones. Using grayscale morphology with two point horizontal structuring element has shown to be very efficient in removing these structures. The modified shorted path algorithm always finds a path through the middle of the implant in both anterior and lateral image, and from this the centre point in 3D is extracted. The orientation in 3D is found by defining a vector through top and bottom point. The experiments have been done by writing macros in ImageJ, and based on these macros a final program will be written in java code.

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