Analysis of radiograph and detection of cardiomegaly

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Abstract - The paper presents the procedure which automatically and reliably determines the presence of heart enlargement, also known as cardiomegaly, from a chest radiograph. We took advantage of some well-established image processing methods and adapted a few of them to meet our needs. Methods which were used include image filtering with convolution masks, segmentation with thresholding and edge detection. The procedure to detect heart and chest cavity boundaries and the corresponding boundary points using modified and custom image processing methods is presented. The final result represents the confirmation or rejection of cardiomegaly.

I. INTRODUCTION

Many medical procedures exist that help doctors set the most accurate diagnosis possible. One of those procedures is radiography, which enables insight into human body. Radiography is one of the most frequently performed medical procedures, usually carried out to examine changes in human tissue. Chest radiographs are used to diagnose conditions affecting the chest cavity, its contents and nearby structures. Until recently, the computer aided analysis of radiographs was impossible due to the lack of digital technology in radiology. Today the use of digital X-ray machines is widely spread and analysis of radiographs was taken to a new level with computer processing [1]. The new technology introduced many advantages, such as speed, accuracy, flexibility and automation [2,3]. But still there is a shortage of analytical software, which could improve the process of diagnosing. Therefore different analysis which could be computer aided, are still done manually [4]. One of those is detection of heart enlargement or cardiomegaly [5,6,7].

The aim of this work is to develop a program, which could quickly and reliably assist doctors with diagnosis of cardiomegaly through a simple user interface.

II. MATERIALS AND METHODS

A. Medical data

In our study we have used a dataset of 47 patients for training and 21 for testing all examined in medical center Grosuplje (Slovenia). All performed X-ray imaging because of various suspected coronary or respiratory diseases. Patients were not examined for cardiomegaly specifically. Radiographs (X-ray images) were all taken in the posteroanterior position and were recorded with a Siemens Vertix digital radiography system, with X-ray tube assembly Optilix 150/30/50 C. Diagnostically useful images were produced and were available in DICOM format with resolution of 4280 x 3520 pixels. For the purpose of image processing, X-rays were converted in JPEG format and downscaled to resolution 1024 x 842 pixels.

B. Methods

The process of detection of cardiomegaly [8] consists of methods which determine some parameters from the radiograph in the specific order:

1. Region of interest (ROI) representing the position of the heart,
2. boundary points denoting the widest part of the heart (see Figure 1: points B and C)
3. boundary points of chest cavity (see Figure1: points A and D) on the same horizontal line as points B and C,
4. the width of the heart (distance between B and C),
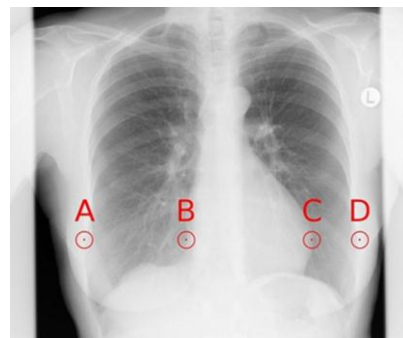5. the width of the chest cavity (distance between A and D).

Figure 1. Reference points, required to determine cardiomegaly

For the process to work, the radiograph must be obtained in a posteroanterior position. Whole chest cavity with its borders must be visible and the spine and heart should be positioned near the center of the image. All our test images met our requirements. Nevertheless radiographs vary to such an extent, that the chest anatomy cannot be precisely determined by some constant parameters.

C. Determining the position of the heart

Due to differences in radiographs, the position of the heart cannot be sufficiently determined based on static parameters. The lower part of the heart is often obscured by the diaphragm. The central part is dimmed by the spine and the upper part is overcasted with veins and bronchi.

The position and visibility of the heart is affected by:

- relative position of the heart in the chest cavity,
- the heart's size,
- horizontal and vertical offset of the body,
- rotation of the body,
- the position of the diaphragm,
- heart and lung pathology,
- the position of the heart in relation to the spine,
- the amount of blood vessels, bronchi and cataract around the heart.

With these factors in mind we have developed a procedure to determine the location of the heart on the radiograph. The steps of this procedure are:

1. calculating average intensity of the image,
2. image blurring,
3. segmentation of the image with thresholding (threshold is adjusted according to the average intensity)
4. determining the location of the heart in the processed image.

D. Calculating the average intensity of the radiograph

The average intensity is required for parameter adjustments in later processing of the radiograph (segmentation [9]). Because we are only interested in the intensity around the center of the image, we omit the outside 20 percent of the frame by calculating the average intensity. By doing this, we accelerate the calculation and avoid possible excessive values, which can often be found in the image border (dark areas or bright x-ray filters).

E. Blurring the radiograph

Radiographs are full of details, such as vessels, bronchi, cataracts and noise, which are insignificant to our purpose and make image processing more demanding. To avoid them as much as possible, our tests showed, it is better to blur [10] the X-ray before further processing. On the other hand, it is crucial to maintain sharp edges of larger organs, such as heart and diaphragm. After extensive testing of different blurring algorithms, we came to a conclusion, that we get the best results using selective blurring. Since we decided to use a rather large convolution mask in our blurring algorithm, we opted to accelerate our algorithm by using two-dimensional blurring with one-dimensional convolution mask. The result of two-dimensional blurring with a mask of size n x 1 is comparable to one-dimensional blurring with a mask of size n x n, but the speed of the algorithm increases dramatically. According to our test results, we chose to use a convolution mask of size 37 x 1 (see Figure 2).

Figure 2.   The result of blurring a radiograph

F. Segmentation of the radiograph with thresholding

In order to locate the heart as precisely as possible, it is best to expose it from the background of the image. To achieve this, the radiograph was binarized using thresholding. The value of the threshold is set dynamically, based on the image average intensity. The reliability of this phase of the processing is crucial, so the value of the threshold is set extremely low. By doing this we get rid of all disturbing factors and artifacts around the heart such as vessels, bronchi and ribs. After this procedure, the white silhouette of the heart is clearly exposed and the surrounding lungs are free of rib and bronchi marks (see Figure 3).
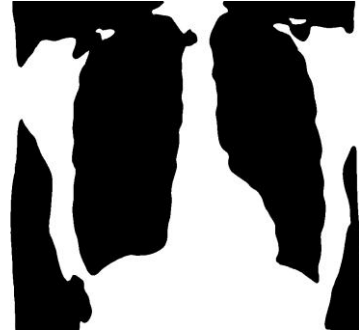

Figure 3.   Radiograph binarization

G. Determining the heart location

After the radiograph is blurred and segmented, precise boundaries of organs cannot be defined, but their location in thoracic cavity can. The first step in determining the heart's location is establishing the position of the diaphragm. The detection of the diaphragm's height is performed on two predefined vertical lines. The algorithm scans both lines and records the lowest detected black pixel on each line. The highest pixel of the two, which is in the lower half of the image, is recorded as the diaphragm's height. Because the shapes of the diaphragm vary, the determination of the heart's position is carried out just above it. The detection is performed on a horizontal line between the previously mentioned two vertical lines. The first two detected white pixels roughly represent the hearts borders. The results of this procedure are precise enough to represent the base for further processing (see Figure 4a and 4b).
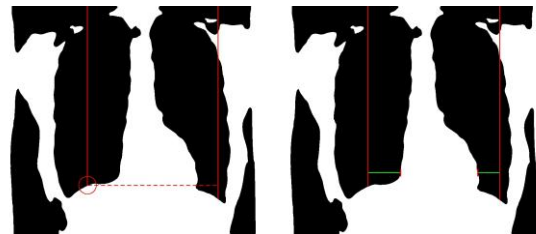

Figure 4.   4a: detection of the height of the diaphragm, 4b: determining the hearts border points

H. Determining the left and right border of the heart

With the two border points calculated in previous step, we get a relatively small area, within which the actual borders are located. For finding the exact boundaries, unprocessed radiograph is used. Minor irregularities are eliminated with the blurring algorithm mentioned before.

The blurring is limited to the area, where the search is performed.

I. Edge detection operator

To find the two vertical borders of the heart we have developed a specific edge detection operator, which detects only the vertical edges. A positive detection of the edge is based on the intensity of the surrounding pixels [11,12]. Best results were achieved with a 21 x 25 pixel filter. This filter enables us to ignore most unwanted edges and small objects in the image, but still filter the significant ones (see Figure 5).
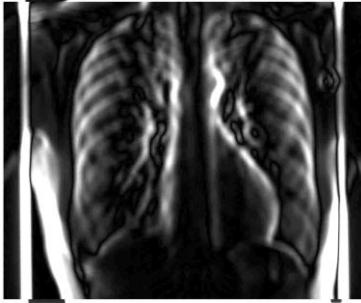

Figure 5.   Application of edge detection operator to a radiograph

J. Finding precise heart boundaries

Our algorithm focuses on finding the right border first (left in the image), which in most cases is hard to determine due to poor visibility and anatomy specifics. The detection is carried out in the area surrounding the left reference point, which defines the heart's location. The strongest edge detected is used as the right border of the heart. The right border defines the vertical line along which the detection of the left border is performed. The strongest edge detected is noted as the left border of the heart (see Figure 6).

Figure 6.   Precise border points of the heart

K. Search for the widest part of the heart

After the distance between heart borders is detected, three possibilities exist - the widest part is above the current border points, below the current points or the current points already lie in the widest part of the heart. These options are exclusive so at least one of these options must be checked. The algorithm searches for the widest part of the heart in the following sequence:

1. Check, if the widest part is above current points
   a. Yes - locate and memorize the widest part
   b. No - continue search below current points
2. Check, if the widest part is below current points

a. Yes - locate and memorize the widest part
b. No - current points are already in the widest part.

To check the border, the algorithm uses a 3 x 10 pixel filter, which still focuses on vertical edges but is smaller and more accurate than the previous one. The search is horizontally and vertically limited by static parameters (see Figure 7 and 8).
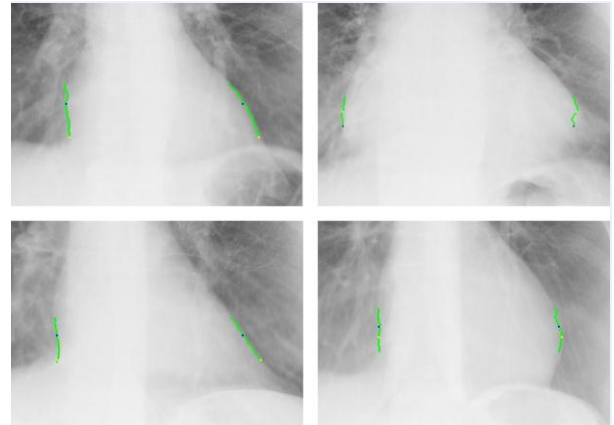

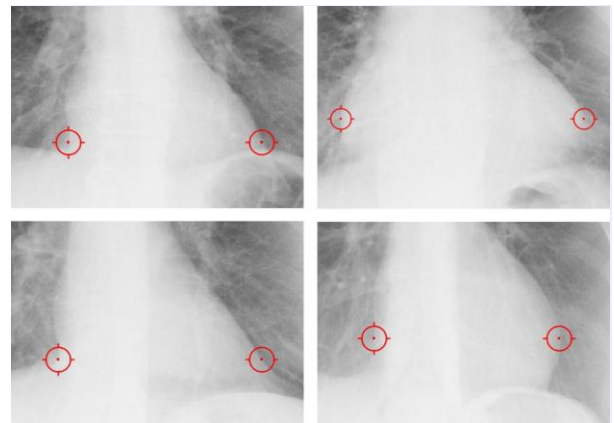Figure 7.   Search for the widest part of the heart

Figure 8.   Detected precise heart borders

L. Determining the borders of the chest cavity

The chest cavity borders are relatively easy to determine. Some of the brightest values on a radiograph can be found where the ribs enclose the cavity at the sides of the body. The algorithm is aimed at finding these bright values near the edges of the X-ray. There is a chance that the radiograph is slightly filtered around the edges (to limit the radiation). The filters are seen as bright stripes on the edges of the image. Therefore the detection of possible filters on the left and right edges is performed before determining the chest cavity borders. The detection of the ribs is performed on the horizontal line connecting the border points of the heart's widest part. The brightest values between the heart and the end of the image or possible filters define the border points of the chest cavity (see Figure 9).
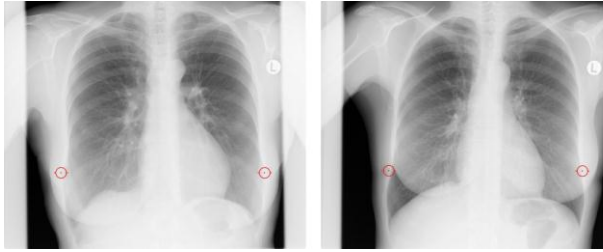
Figure 9. Detected borders of the chest cavity

M. *Distances between the border points*

When all four border points on the same horizontal line are known, the distances between them, are recorded. The distances represent the heart's width (between B and C) and the width of the chest cavity (between A and D). By comparing these measures the relative size of the heart is presented and cardiomegaly is confirmed or rejected.
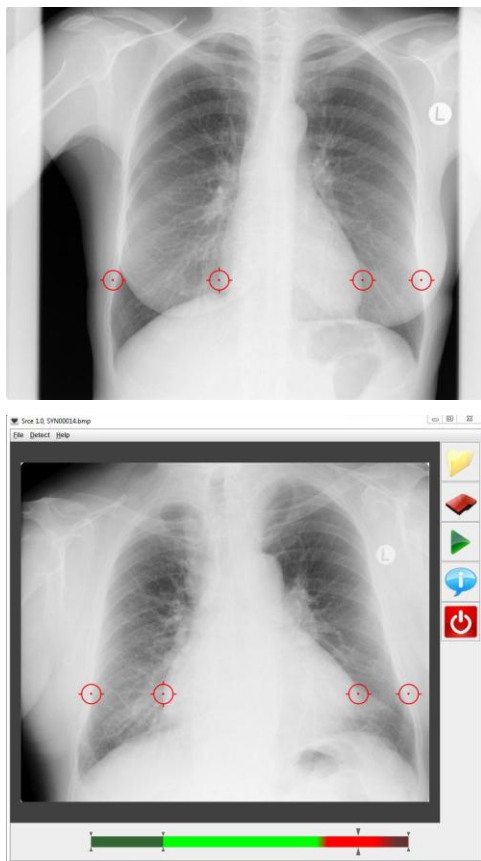

Figure 10. Our program (detected reference points and relative size of the hearth)

III.   RESULTS & DISCUSSION

In this paper we tried to present a program, which automatically and reliably determines the presence of cardiomegaly (see Figure 10). Generally known and some own image processing methods were used. By blurring and segmenting the radiograph the heart's position is defined. A customized edge detection operator is used to determine the heart's and chest cavity's width. The heart's size relative to chest cavity's size is presented. The learning set for developing this procedure consisted of 47 patients. The algorithm was tested on a set of 21 patients. In 14 cases out of 21 test cases we got excellent results, in 3 cases the results were good but still had space for improvement and 4 results were inadequate.

The developed program was presented to the staff of the radiology department at the medical center Grosuplje, who gave a very positive response and encouraged us to develop the method further.

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