Detecting the Respiratory Motion of the Rib from Chest X-Ray Images

Khaing Zar Tun, Hnin Hnin Aye, Myint Myint Sein
University of Computer Studies, Yangon, Myanmar
khaingtunster@gmail.com, hnin2aye@gmail.com, mlm@wwlmail.com

Abstract

A new approach for detecting the respiratory motion of the rib from the 2D X-ray images is proposed. Both the left and right sides of rib have been considered as a side of an ellipse and their radiuses of curvatures are estimated from feature points of the rib. The measurement matrix is built with the corresponding control points of each ellipse. By means of the control points, instead of all points of an ellipse, data capacity and computational times are reduced. The precision of matching pairs of a rib in multiple images is improved. The experiment with X-ray images has been performed and the effectiveness of the proposed technique has been confirmed through the results with acceptable errors. This approach can be applied to examine the chest expansion for inspecting the pulmonary diseases.

Keywords: Respiratory motion of the rib, ellipse point, measurement matrix, thorax, chest X-ray images.

1. Introduction

X-ray is a popular medical imaging modality because it is a safe, non-invasive, versatile, accurate and cost-effective investigation. X-ray is a useful, convenient and complex operation composed of numerous tasks from different areas in the medical field so hospitals and medical centers all over the world used X-ray clinically in such diverse body regions as brain, liver, kidney and the respiratory systems. Detecting respiratory motion of the rib using X-ray image is easy to know the respiratory system of the body and diseases. It has a sensitivity of nearly 100 percent in the diagnosis of diseases.

Recently, the studies of the respiratory movement in the 2D configuration of the chest wall have been paid substantial attention by researchers. The chest or breast shape and position will be changed through the motion of the rib on the occasion of the breathing relative to the contraction of the breathing muscle. There are some related approaches [1-7] to generate and recover the motion of the chest wall and ribs. Cala et al. [3] applied four TV cameras to detect the 86 hemispherical reflective markers arranged circumferentially on the chest wall. Groute et al. [4] also used an automatic motion analyzer, the ELITE system, to investigate the chest wall motion during tidal breathing. Two TV cameras are used in their system to record the 36 markers. Jordanoglou [5] recovered the motion vector of a rib. According to this, the rib rotates around only one axis and its shape doesn't change during breathing. The several points along a rib are parallel to one another and they have a constant direction on successive breathing cycles. We propose a new method for detecting the respiratory motion of the ribs based on our previous approach [1,2]. Each left and right rib pair is considered as an ellipse and its 2D shape and motion are detected. The controlled points on each ellipse are estimated using the ellipse approximation algorithm. In this algorithm the iteration method based on the learning algorithm is employed for minimizing the approximation errors. These control points have reformed the 2D ellipse. Then, the corresponding pairs of control points of each curve are investigated in successive image frames. The measurement matrix has been built by gathering the corresponding points of each ellipse of the X-ray image frames. The shape and motion of a single object can be recovered from the image stream under orthography [7]. In this work, we compute the motion of each rib pair and approximate the average motion parameter of the rib. It is possible to inspect some pulmonary diseases from the chest expansion observed by this approach.

This paper is organized as follows. The structure of thorax, the rib represented by an ellipse from an X-ray image and the overview of the general process are introduced in Section 2. Estimating the motions of the rib with control point of an ellipse is shown in Section 3. The experiments and results are described in Section 4. Finally, the conclusions and discussion are presented in Section 5.

2. Representation of an Ellipse

2.1. General Process

The X-ray images are grabbed by an X-ray radiology device during breathing. The general process of our method for detecting the motion of the rib is shown in Figure 1.

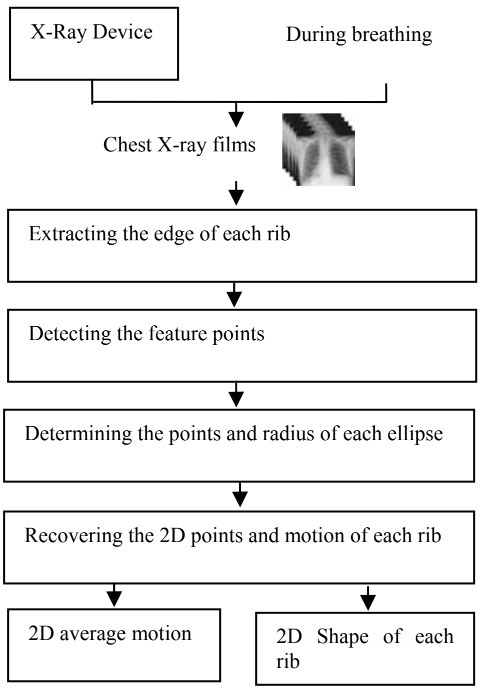


Figure 1. The Design of the Proposed System

2.2. Thorax and X-ray Image Represented by an Ellipse

In this Section the structure of the thorax and X-ray image will be considered. Generally, the thorax formed by the twelve pairs of left-right ribs connected with the spine (backbone) is illustrated in Figure 2. Rib regions are extracted from the X-ray image. Each pair of rib can be represented as an ellipse. An extracted pair of rib 2 in an ellipse shape is presented in Figure 3. The position of each rib will change due to the breathing. Each rib touches the backbone in two places, which are the rib head (caput costae) and process transverses, and each rib rotates centering on the axis, which passes these places [6].

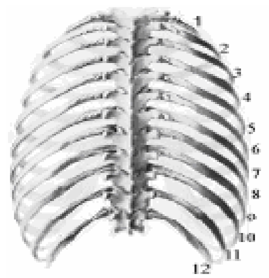
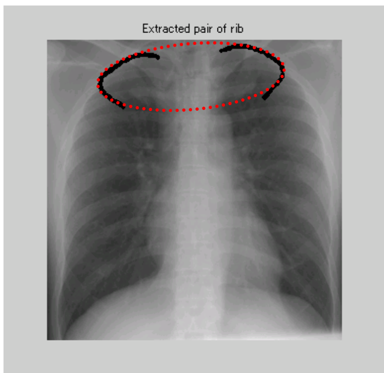
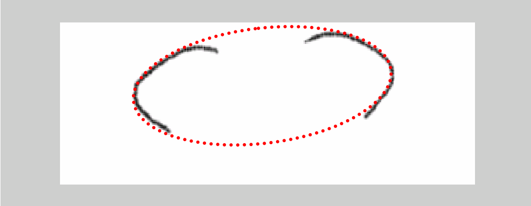


Figure 2. Model of Thorax (Back)



(a) An X-ray Image with an Extracted Pair of Rib



(b) An Extracted Pair of Rib from X-ray Image

Figure3. An Extracted Pair of Rib in an Ellipse Shape

3. Estimating with Control Points of an Ellipse

In this session, a set of control points needs to estimate for representing the feature of an ellipse. Although more than 70 points are included in an ellipse, only four control points for an ellipse are needed for computation. To examine the control points concerning assumed points on a free ellipse must be estimated. The points x_1 and x_2 must be calculated the major axis of an ellipse and then we can calculated the minor axis and the center (h,k) of an ellipse. The general equation of an ellipse with center (h,k) and radius a and b is:

$$\frac{(x-h)^2}{a^2}+\frac{(y-k)^2}{b^2}=1 \qquad (1)$$

$$a^2=\frac{(x_1-h)^2\left[(y_2-k)^2-(y_1-k)^2\right]+(y_1-k)^2\left[(x_1-h)^2-(x_2-h)^2\right]}{(y_2-k)^2-(y_1-k)^2} \qquad (2)$$

$$b^2=\frac{(x_1-h)^2\left[(y_2-k)^2-(y_1-k)^2\right]+(y_1-k)^2\left[(x_1-h)^2-(x_2-h)^2\right]}{(x_1-h)^2-(x_2-h)^2} \qquad (3)$$

$$h=\frac{x_1-x_2}{2}\ ,\quad k=\frac{y_1-y_2}{2} \qquad (4)$$

And so our method uses only control points instead of all points of an ellipse, data amount and computational times will be drastically reduced.

The position of each rib will change due to the breathing. Now, we would like to consider the transformation between each ellipse in the successive image A and B. The motion of the rib can be described by the rotation angle and direction concerning with the rotation axis.

$$A=\Omega B \qquad (5)$$

where the transformation matrix Ω contains the rotation and translation vector components and its can be expressed as:

$$\Omega = (R \mid T) \qquad (6)$$

Then the transformation matrix Ω is obtained from equation (5);

$$A=\Omega B$$

$$AB^{-1}=\Omega BB^{-1}$$

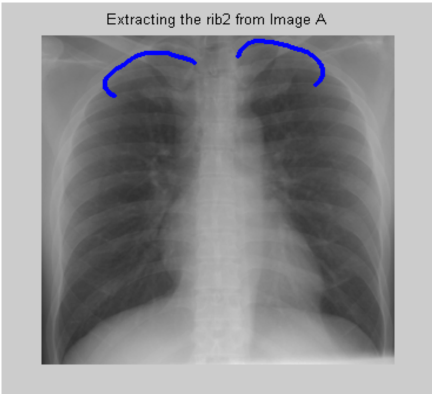
$$AB^{-1}=\Omega I$$

$$\Omega = AB^{-1} \qquad (7)$$

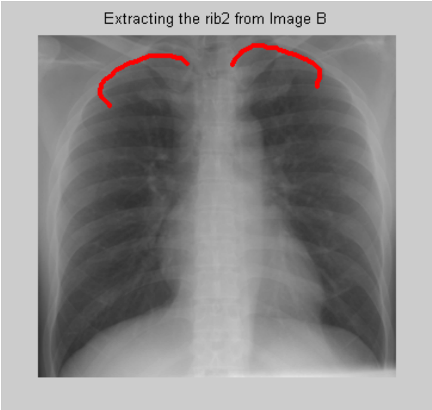
where $\Omega=\begin{bmatrix} r_{11}r_{12}r_{13} \\ r_{21}r_{22}r_{23} \\ r_{31}r_{32}r_{33}\end{bmatrix}$

and $T=[t_1t_2t_3]^T$

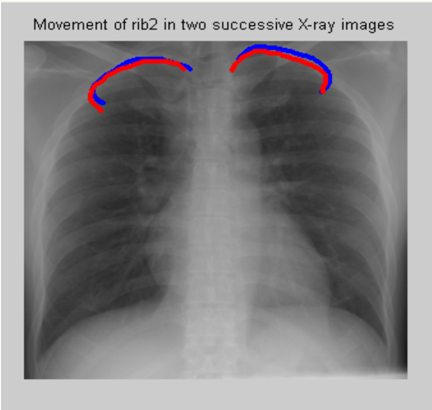
Three characteristic values can be reduced from Ω by the eigen value decomposition. One value will be a real value and others two are complex. The eigen vector relating to the unit value is represented for the direction of the rotation axis. And the rotation angle is computed from two complex values. Figure 4 presents the movement of rib2 between two successive X-ray images.



(a)Extracting the Rib from Image A



(b)Extracting the Rib from Image B



(c)Movement of a Rib between two Successive X-ray Images

Figure 4. Movement of a Rib between two Successive X-ray Images

4. Experiments and results

The chest X-ray images are obtained from the healthy male subjects by the radiology device during respiration. Table 1 summarizes the current performance. The center pixel of the image is (150,150). The distance between a film plate and the radiology device is fixed to 100 cm. The camera model can be considered as a weak-perspective model by the ratio of the object depth and distance from the X-ray device. A PC with Intel(R) Pentium (R)4 CPU 2.66 GHz, and 256 MB of RAM is used in this experiment. Matlab version 6.5 which is the high performance numeric computation and visualization software is employed to analyze the data. Some processing steps of ellipse extraction have been performed with Adobe Photoshop 7.0. Rib regions are extracted from the X-ray image by processing the images. Due to the nature of the rib, the smooth shape of ellipse can't be obtained from the upper and lower edge line of the rib. Rib 1 is difficult to extract separately and rib 10, rib 11 and rib 12 can't be seen clearly in some images. So the ribs 2 to 9 are only considered to extract the lower parts of their edges.

In this experiment, we extracted the region of rib2 from X-ray image and then compare the transformation of rib2 between each successive X-ray images. The simulation of the Ellipse control point estimation for an ellipse has been done and the simulation results are shown in Figure 5. Figure 6 illustrates the transformation between each ellipse shape motion of rib2 in the successive X-ray images. For each ellipse of ribs, the set of points including four control points is examined by the ellipse points finding algorithm. The average computation times for detecting the 2D motion and the drawing of ellipse for each rib are 0.2 sec. The effectiveness of our proposed method was confirmed from the experimental results.

Table 1. Performance of the Subjects and X-Ray Device

Number of subjects	10
Average age	42
Frame rate	Up to 9 frames during 0.3sec
Average depth of the body	17cm
Distance between a film plate and the radiology device	100cm

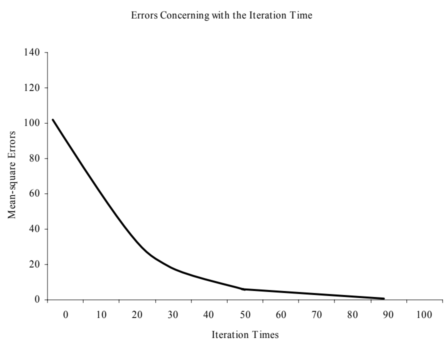


Figure 5. Simulation Results: Errors Concerning with the iteration times

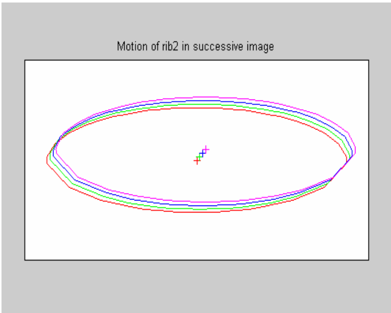


Figure 6. Ellipse Shape Motion of Rib2 in Successive Images

5. Conclusion

This paper described a new method for detecting the 2D shape and motion of the rib. First, the set of points for each ellipse (rib) is being extracted from the different images during breathing. Even through edge of an ellipse has so many points but our method used only four points on an ellipse edge and so data storage, data amount, performance and computation times will be reduced. The accuracy of matching of a rib in multiple images is improved. The advantage of this method is X-ray device desired to investigate the breathing by standing up the patient and it is not necessary to put him on the bed. This approach can be applied to examine the chest expansion for inspecting the pleural diseases such as chronic obstructive pulmonary disease (COPD), tuberculosis, ankylosing spondylitis, and adult respiratory distress syndrome and so on.

Furthermore, we would like to investigate the breathing rate of abnormal people for comparing with these results. It is also possible to analyze the modeling of the respiratory system. Our next work is to detect the 3D shape and motion of rib and to improve the precision of the motion and the shape of a rib with the more points for each higher order ellipse.

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