Automated Vertebral Pose Segmentation based on Level Set Method and Bone Geometric Analysis

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***Abstract*—Vertebral pose segmentation is an important factor in diagnosing bone diseases such as osteoporosis, osteopenia and scoliosis. Low radiation X-ray images are often used to diagnose such diseases. This is done to reduce patients risk exposure on the over dose radiation which may cause from a series of treatments. In this respect, it led to a low accuracy in vertebral pose detection. In this paper, the automated vertebral pose segmentation based on geometric analysis using ellipsoidal wave on x-ray image of human spine. The proposed method consists of two main step. Firstly, in the pre-processing step, gamma correction is an image adjustment technique that used to enhance spine area. Secondly, in the segmentation step, Level Set Method, Edge Estimation and Ellipse Analysis are combined to locate the vertebral pose area. The experimental result can locate the position of each vertebral pose with 92.54% for Precision, 84.40% for Recall and 79.02% for Accuracy.**

Keywords—vetebral pose; edge detection; ellipsoidal wave; geometric analysis; polynomial estimation; low radiation image;

I. INTRODUCTION

Diseases such as back pain, osteopenia and scoliosis can usually happen to people causing from their everyday life behavior. Such habits, for example, lifting too heavy things, wrong sitting pose, lack of exercise and accidents are the causes of such diseases. In addition, aging people are most likely to face such diseases unavoidable. Symptoms of these diseases often could not be easily visible or noticeable by patients at the very first state of symptoms development. Most cases, the symptoms shown after the patients are in the severe state. In such case, the patient may already need a surgery treatment. Therefore, the earlier the symptoms can be diagnosed, the better the alternative treatment can be used instead of surgery. Currently, there are alternative medical diagnosis support tools such as Computer Tomography, Magnetic Resonance and X-ray Machine. These medical equipment have different properties. Some of them can produce a very sharp and clear image quality of the bone structure while some of them cannot. The quality of the image is varied directly with the volume to radiation.

In clinical routine, X-ray Machine is widely used because it is a simple and cheap one. Moreover, the patient will be exposed to a very low level of radiation as compared to other types of machine. In this respect, it means that it can reduce risk on side effect for a long term treatment. However, due to the low volume of radiation, the quality of the image produce by this machine is not good. This led to a difficulty to properly detect the bone structure by specialist. Likewise, this type of image quality also made it difficult to automatically detect by computer vision. This is due to the fact that there is a very small differentiation among intensity of each objects in the image.

A number of image processing techniques has been proposed to overcome such a problem mentioned above. Binoshi Samuvel el al. [1] proposed a mask based segmentation algorithm for automatic measurement of Cobb Angle from scoliosis in X-ray image to find the angle from vertebral spine area and then get the result for more accuracy. But the starting point for the position of each vertebral posed is still set manually. Bagus Adhi Kusuma et al. [2] presented spinal curvature determination from scoliosis X-Ray image using sum of squared difference template matching. This work focuses on the vertebral column shapes: S-shaped or C-shaped. Template matching and Sum of squared difference are used to estimate the position of vertebral. However, a problem of template matching is not suitable for detecting objects which have variety of sizes. Chunming Li et al. [3] proposed distance regularized level set evolution or DRLSE. This DRLSE model based on the gradient method to find the contour of object of interest. Yang Li et al. [4] proposed a novel automatically initialized level set approach based on region correlation for lumbar vertebrae CT image. S. Ruiz-Espaa et al. [5] presented a fully automatic segmentation method of thoracic and lumbar vertebral bodies from Computed Tomography images using Level-Set Based.

II. PROBLEM ANALYSIS

Typically, Dual Energy X-Ray Absorptiometry Machine or DEXA, generates an X-Ray image with different variation of contrast depended upon the volume of radiation used for diagnosis different symptoms. Normally, for long term treatment, the patient will be exposed with low volume of radiation. This is done to reduce risk of overdose explosion that may cause from a series of treatment in certain cases such as osteoporosis disease. As a consequence, a low-radiation image may contain with a lot of noises. Moreover, the bone structure of each person is varied. This may due to the weight, age and congenital disease. This can lead to the loss of certain

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information of the vertebral spine. These situations brought forward a number of diversified patterns on the vertebrae pose that made it difficult to analyze the image either manually or automatically. In the case of manually segment the vertebrae pose, a specialist may need a longer time to draw the boundary of each pose for low quality image. For the case of automate process, an attempt using only single algorithm is almost impossible. Fig. 1, showed an image of lumbar section that contained various patterns at the joint point area of each pose.

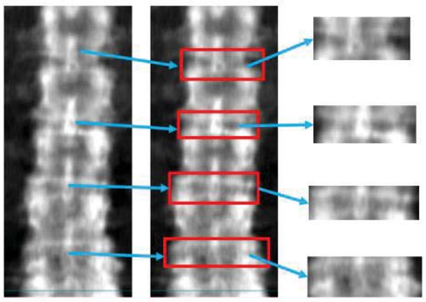


Fig 1. An example region of joint between each vertebral pose.

III. METHODOLOGY

In this section, the proposed method to locate the vertebrae pose is discussed. There are two main steps. The overview of the proposed method is illustrated in Fig. 2.

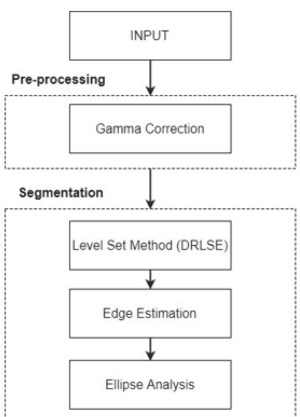


Fig 2. Overview of the proposed method

A. Pre-processing

Gamma Correction: In this research, Gamma Correction is applied to enhance an image to distinguish foreground from background. With this technique, a number of noises can be eliminated. In theory, a value of gamma correction less than 1 will increase the brightness while a value more than 1 will decrease the brightness.

The proposed method used a gamma value of 0.4 to generate a result as shown in Fig. 3.

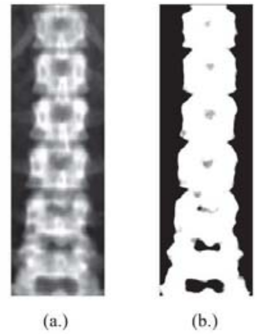


Fig 3. (a.) Original image (b.) The result from pre-processing step.

B. Segmentation

Level Set Method: Level set methods have been widely used in image processing and computer vision. The main idea of the level set is to detect a point where there is a differentiation between intensity. By detecting this kind of points, the contour of object can be revealed. In this work Distance Regularized Level Set Evolution (DRLSE) [3] is applied to find a boundary of vertebral column. The general equation of DRLSE can defined by $\phi : \Omega \rightarrow \Re$ is LSF on a domain Ω. Energy function $\varepsilon(\phi)$ written as

$$\varepsilon(\phi) = \mu R_p(\phi) + \varepsilon_{ext}(\phi) \tag{1}$$

Where $R_p(\phi)$ is the level set regularization term, μ is coefficient of the distance regularization term and $\varepsilon_{ext}(\phi)$ is External Energy. The level set regularization term $R_p(\phi)$ is defined by

$$R_p(\phi) = \int_\Omega p(|\nabla\phi|)dx \tag{2}$$

Where p is a potential function. While Edge based active contour in DRLSE is defined by function g as shown in Eq. 3

$$g = \frac{1}{1 + |\nabla G_\sigma \times I|^2} \tag{3}$$

Where I is the output image from Section A, G_σ is Gaussian kernel with a standard deviation σ. In Eq.3 used to smooth the image. For LSF $\phi : \Omega \rightarrow \Re$ in our work defined an energy function $\varepsilon(\phi)$ by

$$\varepsilon(\phi) = \mu R_p(\phi) + \lambda L_g(\phi) + \alpha A_g(\phi) \tag{4}$$

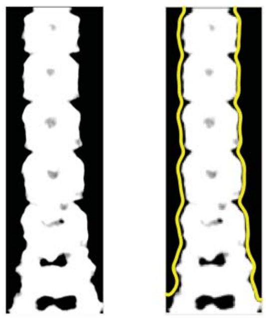
Where $\lambda > 0$ and $\alpha \in \Re$ are the coefficients of energy function, $L_g(\phi)$ and $A_g(\phi)$ with are defined by

$$L_g(\phi) = \int_\Omega g\delta(\phi)|\nabla\phi|dx \tag{5}$$

And

$$A_g(\phi) = \int_\Omega gH(-\phi)dx \qquad (6)$$

Where δ and H are the Dirac delta function and the Heaviside function. The $L_g(\phi)$ computes the line integral of the function g and $A_g(\phi)$ computes a weighted area of the region.



(a.) (b.)

Fig 4. (a.) The result from Gamma Correction (b.) The result from DRLSE.

Edge Estimation: A result received from Level Set Method provides an outline contour of the vertebral spine. The proposed method, then applied edge estimation technique called Polynomial Curve Fitting to smooth out the contour outline before generating the center line of the bone structure. Polynomial Curve Fitting can be defined as shown in Eq. 7 and Eq. 8

$$P(x) = P_1x^n + P_2x^{n-1} + \ldots + P_nx + P_{n+1} \qquad (7)$$

$$y = P_1x^n + P_2x^{n-1} + \ldots + P_nx + P_{n+1} \qquad (8)$$

Where $P(x)$ is the coefficient, y is the value of a polynomial, n is the degree of polynomial. In this study, a degree is equal to 3. This is because the spine structure have a curved like shape.

Ellipse Analysis: Once the center line of the bone structure was retrieved, ellipse shape objects are generated using a point in center line as a center point of each one. The proposed method used ellipse analysis to differentiate among different patterns of bone structure which are distinguished by its intensity and properties of each specific cases. Ellipse equation is calculated from

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \qquad (9)$$

Where x and y is coordinate point, a and b is axis length. The axis that has a bigger value is called a major axis moreover and another is called minor axis. The center of the ellipse shifted along the position of the center line of the bone structure.

A region of ellipse can be computed from

$$\frac{(x - x_c)^2}{a^2} + \frac{(y - y_c)^2}{b^2} \leq 1 \qquad (10)$$

Where x_c is a center along x-axis, y_c is a center along y-axis. The density of ellipse we called DE can be calculated from

$$\mathrm{DE} = \frac{\sum_{i=1}^{n}(Ic_i)}{n * level} \qquad (11)$$

Where DE is density, Ic is an intensity value of each pixel inside each region of interest, n is size of an area, $level$ is a color value which has the maximum value of 256.

However, ellipse analysis does not consider only the density information of overall ellipse area, but also consider the density of circle patterns within each ellipse as shown in the following cases.

Pattern #1: Three Adjacent Circles which has diameter of each circle equal to minor axis, where its center point located at the center of the ellipse as shown in Fig. 5.

Fig 5. A pattern of three circle insides the ellipse

The density of first case we called Case1 can be calculated by

$$Case1 = \frac{\sum_{i=1}^{3} C_i}{3} \qquad (12)$$

Where C_i is density of circle can be computed in Eq. 11

Pattern #2: Two Circles at far sites of the edge of ellipse as shown in Fig. 6.

Fig 6. A pattern of the circle on the edge of ellipse in the second case.

The density of second case we called Case2 can be calculated by

$$Case2 = \frac{C_1 + C_2}{2} \qquad (13)$$

Where C_1 and C_2 is density of circle

Pattern #3: Two Circles in between Pattern #1 and Pattern #2 as shown in Fig. 7.

Fig 7. A pattern of the circle the located between Case1 and Case2.

The density in the third case we called Case3 can also be calculated using Eq. 13. The algorithm of ellipse analysis can be summarized as follows.

1: **Initial four parameter of ellpise(e) in vertebral spine.**
Let *Center* is center line of the bone structure, *Major* is size of vertebral in x-axis *Minor* is 20, *Angle* is 0
2: **Compute density in ellipse(e).**
Let *N* is a number of ellipse.
For each the ellipse(e) between 1 to *N*. Computed as follows:
DE(e), Case1(e), Case2(e), Case3(e)
3: **Create label of each ellipse(e).**
For each the ellipse(e) in vertebral spine:
If *Case1* in ellipse(e) $>$ *Case1* in ellipse(e+1) **then** set *Label(e)* is 1
Else set *Label(e)* is 0
4: **Adjust label in each ellipse(e).**
For each ellipse(e) in vertebral spine:
a) **If** $Label(e) = 1$ **and** $Label(e+1) = 1$ **then**
If $Case2(e) < Case2(e+1)$ **then** set *Label(e)* is 0
Update Label
For each ellipse(e) in vertebral spine:
b) **If** $Label(e) = 1$ **and** $Label(e+1) = 1$ **then**
If $DE(e) > DE(e+1)$ **then**
Collect ellipse(e+1) in *Idx*
Else Collect ellipse(e) in *Idx*
5: **Adjust label between spacing distance in each ellipse(e).**
$D = Idx(k+1) - Idx(k)$
Let *k* is number of member in *Idx* and *D* is distance of the elliptical
a) **If** $D = 2$ **then**
Collect minimal *DE* of ellipse range between *Idx(k)* and *Idx(k+1)* in *List*
Else Update *Idx(k)* in *List*
Repeat a) **until** computed all element in List
b) **If** $D = 3$ **then**
Collect minimal *Case3* of ellipse range between *Idx(k)* and *Idx(k+1)* in List
Else Update *Idx(k)* in *List*
Repeat a) **until** computed all element in List

IV. Experimental Result

From the lab scale experimental on dataset of 50 X-ray images obtained from local university hospital generated by DEXA machine revealed a reasonable result as shown in Fig. 8. Each lumbar spine image composed of T12 and L1 to L4 which has 5 vertebral poses. The proposed method aimed to detect each vertebral pose of the lumbar spine. The proposed method used Precision, Recall, and Accuracy Rate to evaluate performance.

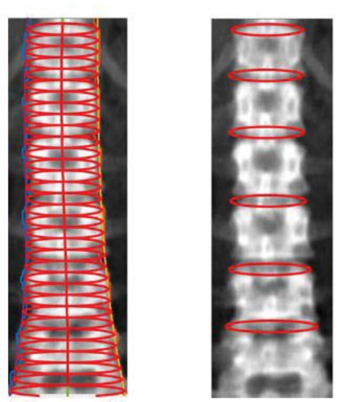


Fig 8. (a.) An ellipsoidal wave in vertebral spine without overlapping area (b.) A final result from ellipse analysis algorithm.

The experimental results are compared with the ground-truth provided by a hospital technical specialist. The performance evaluation indicated that the proposed method obtained 92.54% for Precision, 84.40% for Recall, and 79.02% for Accuracy.

V. Conclusion

In this research, an automated vertebral pose segmentation based on geometric analysis is proposed. The proposed method can automatically segment the vertebral pose in a normal environment. The proposed method used geometric features such as an ellipse and circle for finding the location of each vertebral pose. There are two main steps. Firstly, pre-processing step used Gamma Correction to eliminate background and noises. In next step, Level Set, Edge Estimation and Ellipse Analysis methods are used to segment vertebral pose on the images. The results of our proposed method are compared with ground-truth generated by hospital specialist. The result shown that our approach can locate the position of each vertebral pose with 92.54% for Precision, 84.40% for Recall and 79.02% for Accuracy. In future work, the proposed method will be modified to attempt those special cases on complex environment image and a curved-like vertebrae bone image.

VI. Acknowledgement

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VII. References

[1] B. Samuvel, V. Thomas, M. M. G. and R. K. J., "A Mask Based Segmentation Algorithm for Automatic Measurement of Cobb Angle from Scoliosis X-Ray Image," 2012 International Conference on Advances in Computing and Communications, Cochin, Kerala, 2012, pp. 110-113. doi: 10.1109/ICACC.2012.24

[2] B. A. Kusuma, H. A. Nugroho and S. Wibirama, "Spinal curvature determination from scoliosis X-Ray image using sum of squared difference template matching," 2016 2nd International Conference on Science and Technology-Computer (ICST), Yogyakarta, 2016, pp. 29-34. doi: 10.1109/ICSTC.2016.7877343

[3] C. Li, C. Xu, C. Gui and M. D. Fox, "Distance Regularized Level Set Evolution and Its Application to Image Segmentation," in IEEE Transactions on Image Processing, vol. 19, no. 12, pp. 3243-3254, Dec. 2010. doi: 10.1109/TIP.2010.2069690

[4] Y. Li, W. Liang, J. Tan and Y. Zhang, "A novel automatically initialized level set approach based on region correlation for lumbar vertebrae CT image segmentation," 2015 IEEE International Symposium on Medical Measurements and Applications (MeMeA) Proceedings, Turin, 2015, pp. 291-296. doi: 10.1109/MeMeA.2015.7145215

[5] S. Ruiz-España, A. Díaz-Parra, E. Arana and D. Moratal, "A fully automated level-set based segmentation method of thoracic and lumbar vertebral bodies in Computed Tomography images," *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Milan, 2015, pp. 3049-3052. doi: 10.1109/EMBC.2015.7319035