Development of Portable Real-time Instrument for Three-Dimensional Measurement of Scoliosis ：Three-dimensional curve of spinous process

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Abstract

The purpose of this study is to develop a scoliosis diagnostic instrument which is mainly designed for schools or rehabilitation settings. It provides a portable and an instant three dimensional spine curvature image unlike the traditional diagnostic method. This diagnostic instrument is non radioactive and able to measure the changes in the three dimensional spine curvatures.

Using simple mathematical formula to calculate algorithms of space coordinate, which improves the present traditional spine detection method, and utilize the computer to automatically estimate the severity of the scoliosis and curvature type. This system use palpation, two Webcams to capture two parallel images of "coordinate converter" in the space. Collocate digital image processing, and system of two- dimensional image is transferred to the three-dimensional space coordinate, algorithm of artificial neural networks, for calculating the coordinates of the three-dimension spinal space. Link the line by constructing the curvilinear motion of three-dimensional spinal space. The changes in the three-dimensional space curve allow the estimation of the spinal deformities, such as scoliosis, humpback, and rotation. The contours of three-dimensional space, is from the algorithm calculations and then interpret the severity or type of the resulted spinal curvature.

Keyword: scoliosis; Cobb angle; artificial neural network ; reverse engineering

1. Introduction

Scoliosis is the most common form of abnormal spinal deformity found in adolescence. This condition affects between 2% and 4% of adolescents, and between 70% and 80% of these cases have an unknown cause. Scoliosis is a deformity of the spine that involves abnormal lateral curvature and rotation of the spine in a three dimensional space and usually causes noticeable trunk distortions [1]. When one becomes scoliosis, the spine often deforms in the shape of letter "S" or "C," and it causes oppression of inner organs such as lungs and a heart resulting in ~~heavy~~ lumber pain or fatigue. In general, patients with curve of less than 30◦ are untreated. Patients with curves between 30◦ and 44◦ who are still growing may be treated with orthotic bracing. The main goal of orthotic bracing is to stop progression of deformity [2]. Patients with curves of 45◦ or more are likely to require surgical intervention [1]. At the moment, there are several different kinds of methods are used to measure scoliosis. Forward-bending test is a painless examination traditionally performed on children, but this test is neither reproductive nor objective. Moreover, the inspection takes up a lot of time when applied to medical examination in schools. Radiographs are the traditional tools for assessing idiopathic scoliosis. However, there is increasing concern about the carcinogenic risks associated with them.

Radiographic methods measure only the distortion of the spine in a single plane and a second radiograph is required to extract three-dimensional information. Several research utilized motion analysis to stick marker onto the body both sides of joint. Utilized VICON motion analysis tool to build and construct whole body model, and distinguish the severity of scoliosis [3]. The researcher utilizes the motion analysis and force plate to study the severity and analyses the dependence with curved center and side [4]. But these methods must all be examined in motion analysis laboratory, which is a very inconvenient way to examine scoliosis. Imaging techniques have been used to help to identify and interpret the scoliosis deformity [5-9]. Moire' topography, the integrated shape imaging system (ISIS) and various optoelectronic and magnetic techniques have been employed to improve the three dimensional visualization of the spine. These techniques have focused primarily on the resultant back surface shape and rib hump geometry, and have not effectively described the global effect of the scoliotic spine in standing posture.

Reviews of above-mentioned discussions, the traditional methods are unable to examine the objective quantization of data clearly. Traditional radiographic increases carcinogenic risk and single one is unable to present three-dimensional coordinate of space [10]. Techniques of digital image processing are unable to describe the object surface form and lack perfect degree, and needing to algorithm complicatedly. There are some disadvantages: the high expense in fabric cost, difficult to operate, and it needs specialized expertise.

So, in this study, the detection method of scoliosis provides a simple and easy way with low cost to solve the above mentioned disadvantages of the current detection methods. This study can been measure curve of spinous and process quickly in three-dimensional space instantly.

2. Methods

In this research, the detection method of scoliosis can be divided into three parts: (1) Obtain the spinal space position, (2) Setting-up and analysis of the spinal curvature, and (3) Analysis and diagnosis of the clinical meaning of the curve.

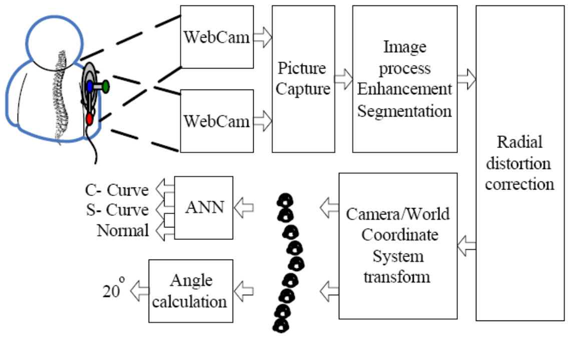


Figure 1.System flow sheet

2.1 Obtain the spinal space position

Utilize ' Three-dimensional space coordinate device ' made by oneself, by ways of palpation (Fig2.)Look for some characteristic positions of the spine from cervical vertebrae to lumbar vertebrae along the backbone, when find the characteristic positions, press the coordinate device to body, and the switch in the coordinate device will turn on two parallel Webcams to capture the space image of this coordinate device.

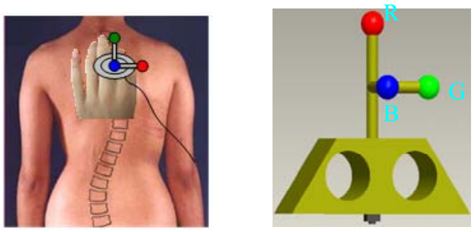


Figure 2. A, palpation; B, "coordinate converter"

Utilize two-dimensional image coordinate and algorithm of performing of the three-dimensional space coordinate, can calculate the three-dimensional coordinate in the space position of spine. It includes three parts ~~here~~: three-dimensional coordinate device, digital image processing, and the space coordinate algorithm.

2.1.1 Three-dimensional coordinate device

While looking for the position of a point in space, we must set up a device with referencing coordinated system to represent the three axes of x, y and z in space. To set up this three-dimensional coordinate device, we use three colors which are red, blue and green to represent the three directions of axis of x , y and z in space. Using this three-dimensional coordinate device and Webcam that obtain from the market, we can capture the coordinated movement of referenced points in space.

2.1.2 Digital image processing

We use National Instruments LabVIEW 7.1 as the development setting, but the efficiency in calculating algorithm is poor, so we utilize Microsoft Visual Basic 6 to write the Visual Basic control of algorithm of digital image processing, and then use the ActiveX function of National Instruments LabVIEW to call out the control one to calculate the two-dimensional image coordinate of the three axis (RBG) of three-dimensional coordinate device.

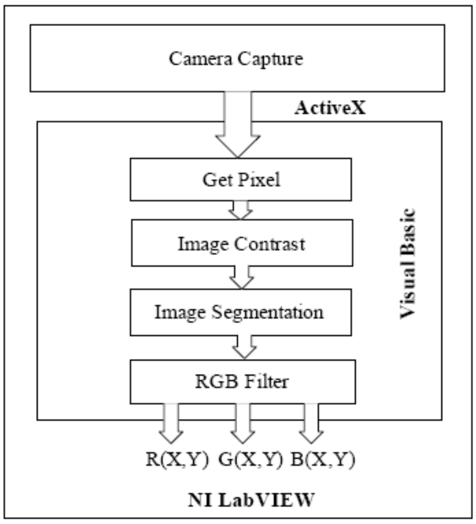
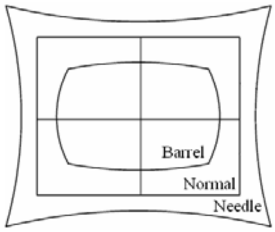


Figure 3.Image processing

However, because of the restriction of sphere form of the Camera, the image that captures from it result in twisted image (Fig4) and it will cause an error during transferring the coordinate. So, we utilize ANN (artificial neural network) to revise the error of this problem.



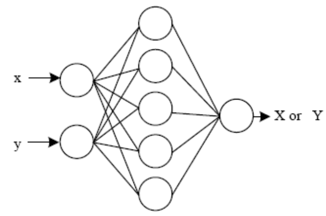


Figure 4.Image Distortion **Figure 5.ANN correct**

We use Scale Conjugate Gradient Algorithm to train the ANN (fig5), and there are two input layers, five hidden layers and one output layer of EBP (Error Back Propagation).The condition is:

$$E = \frac{1}{2}\sum_k (d_k - y_k)^2 < 0.01$$

d_k is the goal value and y_k is the output value of training.

2.1.3 Algorithm of transferring from image coordinates to space coordinate

From Rafael C. Gonzalez, 1992, if we need to obtain object (X, Y) information (Fig6) in space. First we should get the information of the imaging depth of Z direction of the object in space. So if we can get the coordinated value of z axis, then we can calculate the coordinated value of x, y on space. The formulae as follows:

$$Z = \lambda - \frac{\lambda B}{x_2 - x_1}$$

$$X = \frac{x}{\lambda}(\lambda - Z)$$

$$Y = \frac{y}{\lambda}(\lambda - Z) \qquad (1)$$

λ : focal distance； B : Two WebCam centre distance.

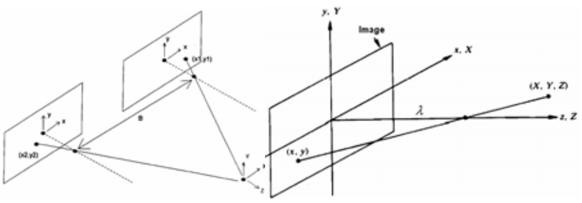


Figure 6.Two- dimensional image is transferred to the three-dimensional space coordinate

Utilize the formulae as mentioned above; we can calculate the coordinated value of three axes (RGB) of the coordinate device.

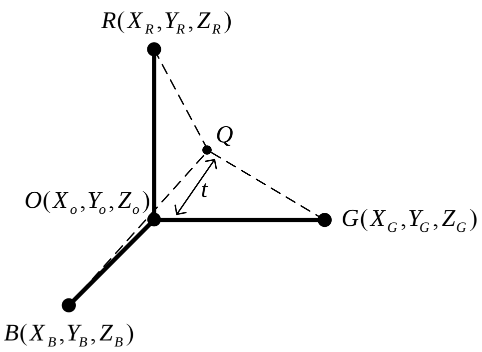


Figure 7.Relation that R(X,Y,Z),G(X,Y,Z),B(X,Y,Z) and O(X,Y,Z)

However, RGB coordinate value only represents the space changes with each other. It does not locate position of switch basic coordinate in the space. But the relation in basic point was known (distance: 3cm), and all present the right angle. So, we can derive space coordinate value of point O by space vectors deductive formula, and point Q is one point that one line which point O perpendicular to the ΔRGB level cross to the level. （Figure 7）

$$\alpha_1 = X_B - X_R; \beta_1 = Y_B - Y_R; \gamma_1 = Z_B - Z_R$$
$$\alpha_2 = X_G - X_R; \beta_2 = Y_G - Y_R; \gamma_2 = Z_G - Z_R$$
$$X_o = \frac{X_R + X_G + X_B}{3} + \begin{bmatrix} \beta_1 & \gamma_1 \\ \beta_2 & \gamma_2 \end{bmatrix} \times t$$
$$Y_o = \frac{Y_R + Y_G + Y_B}{3} + \begin{bmatrix} \gamma_1 & \alpha_1 \\ \gamma_2 & \alpha_2 \end{bmatrix} \times t$$
$$Z_o = \frac{Z_R + Z_G + Z_B}{3} + \begin{bmatrix} \alpha_1 & \beta_1 \\ \alpha_2 & \beta_2 \end{bmatrix} \times t$$
$$(X_o - X_R)^2 + (Y_o - Y_R)^2 + (Z_o - Z_R)^2 = 9$$
$$(X_o - X_G)^2 + (Y_o - Y_G)^2 + (Z_o - Z_G)^2 = 9$$
$$(X_o - X_B)^2 + (Y_o - Y_B)^2 + (Z_o - Z_B)^2 = 9 \qquad (2)$$

2.2 Setting-up and analysis of scoliosis curvature

Receive the coordinate value of X, Y and Z which changing in the space of three-dimensional coordinate device. Connect coordinate value of each point can show three-dimensional space changes of the spinal curvature.

2.3 Analysis and diagnosis of the spinal curvature for clinical meaning

In order to analyze the clinical meaning and interpret, analyzed and interpreted each coordinate device automatically in the coordinate position in the space. It can differentiate into two categories and calculate the angle of scoliosis of the curved side.

ANN's group of learning vector quantization (LVQ) will been trained. Result will been normalized for input; Output can differentiate what type of scoliosis curvature is (C, S, Normal) (Figure 8).

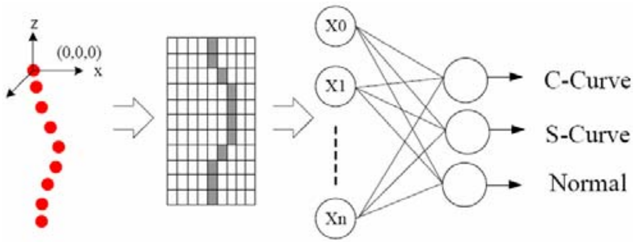


Figure 8.Leraning Vector Quantization Ann

Calculate side curved angle way of utilizing three-dimensional coordinate result, look for crooked place of vertebra most.

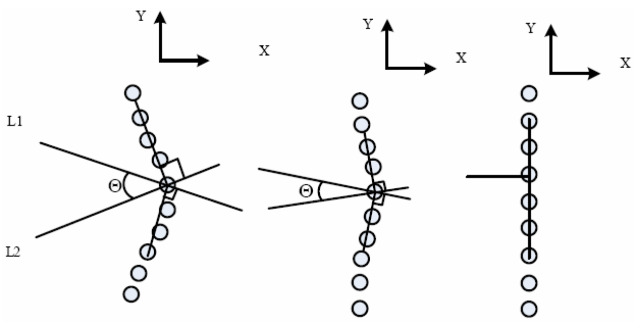


Figure 9. Angle of scoliosis calculating

$$L_1 = a_1 x + b_1 y + c_1 = 0$$

$$L_2 = a_2 x + b_2 y + c_2 = 0$$

$$\Theta = Cos^{-1} \frac{a_1 a_2 + b_1 b_2}{\sqrt{(a_1^2 + b_1^2)(a_2^2 + b_2^2)}} \quad (3)$$

3. Result

Experimental result, able to calculate the three-dimensional changes in the space coordinate of coordinate device. Simple algorithm and digital image processing and constructs the three-dimensional curvature of spine.

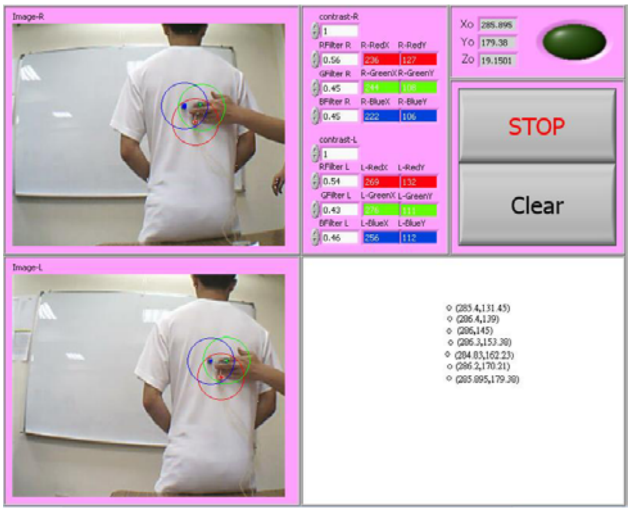


Figure 10. Experiment course

Point	X	Y	Z
1	285.4	131.45	18.4
2	286.4	139	17.6
3	286	145	17.2
4	286.3	153.38	17.8
5	284.83	162.23	18.4
6	286.2	170.21	18.9
7	285.89	179.38	19.15
8	286.45	186.43	19.1
9	286.223	193.512	18.8
10	285.932	200.65	19.2
11	286.42	205.34	19.6
12	284.6	21.03	18.9

Table 1.Result

4. Conclusion

In the course of the experiment, factors of light of the environment and color complexity of the background are great influences of the results, thus the need of time consuming parameter adjustments of digital image processing manually (contrast ratio, thresholding value).

The calculation of the angle and traditional Cobb Angle methods are different in this research, but still can measure the severity of scoliosis, the angle measured increases as the curve become greater as well, but how to define the angle, still need further studies.

Build and construct 3D curvature, allows study of the changes on three-dimensional space of scoliosis. X-Y direction can interpret the type and angle; Y-Z direction can interpret the severity of humpback. Because we believe, scoliosis not only causes influence on X-Y direction, but also causes a great influence on Y-Z direction. Unlike the traditional method which only deal with the angle of X-Y and type, to diagnosis scoliosis.

Figure 11. coordinate converter

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