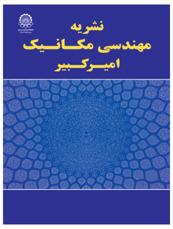

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Three-dimensional surface capture from the back anatomy to quantify three-dimensional vertebral column curvatures without using anatomical markers

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ABSTRACT: Although X-ray imaging is a precise method for measuring vertebral curvature, the radiation dose that patient receives may be detrimental for the body. The purpose of this study is to introduce a non-invasive method based on surface data acquisition to determine vertebral curvatures in three-dimensional space. In this method, infrared depth-sensing cameras are used to generate a 3D point cloud from the patient's back surface. To analyze the topographic map obtained from the back surface, first of all, the anatomical landmarks are determined. These landmarks are necessary for transferring the point cloud data into the frontal plane and make the results free of small setup errors of the sensor. Then, the central position of each vertebra is estimated and the vertebral curvatures are calculated by Cobb's angle method. A review of similar past studies and our case study results demonstrate that estimation of vertebral curvatures from back topographic map is possible. Accordingly, can be said, this non-invasive, inexpensive and portable method with acceptable results can be used in clinics and orthopedic centers for monitoring and screening of scoliosis patients.

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1- Introduction

Lateral deformity of the spine on the frontal plane is called scoliosis. In many cases, this complication is associated with rotation of the vertebrae in the horizontal plane and abnormal curvature in the sagittal plane [1]. Advanced abnormalities of the trunk and spine, in addition to disrupting the physiological function of individuals, also affect appearance, and usually, the first reason for children and adolescents to seek treatment is appearance and beauty issues [2]. The effectiveness of treatment protocols in these patients is assessed through continuous monitoring of the curvature of the spine [3]. Therefore, accurate and reliable measurement of spinal curvatures is necessary for the physician to follow the treatment process [4].

One of the most widely used and, of course, invasive methods for measuring scoliosis is the radiographic method, which is the gold standard for assessing postural abnormalities [5]. The higher prevalence of scoliosis in adolescence and the greater sensitivity of this spectrum to X-rays [6] indicate the need to restrict radiation.

Non-invasive alternatives for estimating spinal curvature include the check of dorsal surface topography methods such as scoliometer, flexible ruler, stereophotogrammetry, laser triangulation, and ultrasound, each of which has advantages and disadvantages. Rasterstereography is another non-invasive method based on structural lights that has been proposed to estimate spinal deviations [7]. Unlike rasterstereography, InfraRed (IR) depth gauge cameras are relatively inexpensive systems capable of creating continuous cloud points of the desired surface.

Therefore, the purpose of this study is to introduce the process of using IR depth gauge cameras as a non-invasive method to investigate trunk and spine anomalies with low cost and desirable accuracy. One of the most important innovations of the current system is to perform scanning in complete darkness without the need to install markers on anatomical landmarks, which eliminates the need for a skilled operator.

2- Methods

2.1. Recording three-dimensional data from the back surface

IR depth gauge cameras, such as the Kinect, are equipped with a depth gauge sensor and a video camera and can combine the information of two sensors to present the scanned surface as a three-dimensional superpoint. Another output of this system, which uses only the IR sensor, is a matrix of distance information, the dimensions of which depend directly on the resolution of the sensor. Due to the 424 by 512 pixel resolution of the depth gauge sensor and the 60 and 70 degree field of view in the top-bottom and left-right directions, respectively, Eqs. (1) and (2) were used to create superpoints in three-dimensional space[8].

$$[X]_{m,n} = \left[\frac{\left(m - \frac{M}{2}\right) \times Z_{m,n}}{\cot(35) \times \frac{M}{2}} \right] \tag{1}$$

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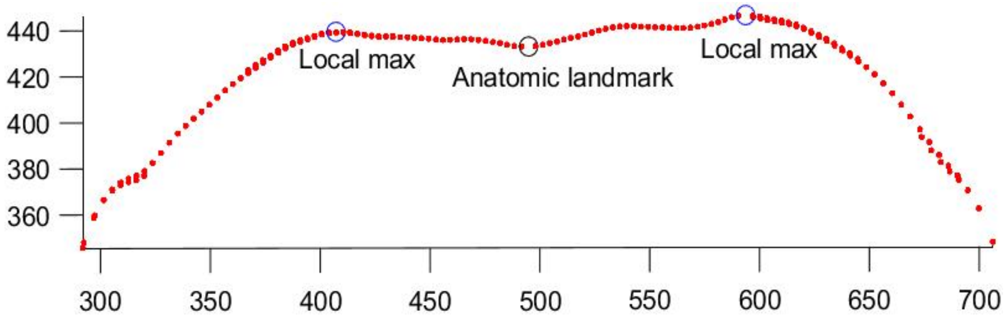

Fig. 1. Landmark identification by finding the valley between two local peaks in each sector

$$[Y]_{m,n} = \left[\frac{\left(n - \frac{N}{2}\right) \times Z_{m,n}}{\cot(30) \times \frac{N}{2}} \right] \tag{2}$$

In Eqs. (1) and (2), *m* and *n* are the pixel numbers in the left-right and up-down directions, respectively. *M* and *N* represent the maximum number of pixels in both directions and *Z* is the distance from the sensor, which with *X* and *Y* form the three-dimensional components of superpoints in millimeters. Also, 30 and 35 were one-half of the camera field of view in the top-bottom and left-right directions, respectively.

Then, by obtaining superpoints in the reference device, the points in the patient's back area were separated and the Gaussian filter was used to reduce the errors in the superpoints.

2.2. Identifying landmarks

The first step after extracting the superpoints from the patient's back is to identify the landmarks to estimate the curvature of the vertebrae. For this purpose, it is necessary to analyze the topographic map of the back with a mathematical approach.

The back of the vertebrae, which are easily recognizable by touch, are called shock absorbers. Given that these spinous processes are lower than other adjacent points on the horizontal plane [9], they can be selected as landmark beads. Based on this, the position of maximum values local in each sector was identified and the valley between these two peaks was estimated as the position of the spinous process (Fig. 1).

2.3. Identifying position of center of the beads

Due to the relationship between the rotation of the back surface and the rotation of the vertebrae, it can be used to identify the center of the vertebrae. Based on this, we obtain the normal vector of each sector on the horizontal plane at the location of the spinous processes. The value of the angle between the normal vector and the sagittal axis (*Z*) in the corresponding sector indicates the value of the vertebrae rotation in the horizontal plane. Then, by having the length of the vertebrae (*L*) and assuming the alignment of the normal vector and the longitudinal direction of the vertebrae, it is possible to obtain the position of the center of the joints.

Accordingly, if $S = (x_s, y_s, z_s)$ indicates the three-dimensional coordinates of the spinous process on the skin surface, $M = (x_m, y_m, z_m)$ that represents the three-dimensional coordinates of the center of the bead is obtained through Eq. (3)[10].

$$\begin{aligned} x_m &= x_s + \Delta x = x_s + L \cdot \sin\varphi \\ y_m &= y_s \\ z_m &= z_s + \Delta z = z_s + L \cdot \cos\varphi \end{aligned} \tag{3}$$

In Eq. (3), φ bead rotation angle is in degrees on the horizontal plane. Eq. (4) was used to calculate the distance from the center of the vertebrae to skin surface (*L*).

$$L(l_s) = 0.132 \cdot T + 0.035 \cdot l_s \tag{4}$$

In this equation T Indicates the length of the spine in meters, which is obtained by calculating the distance between the last vertebra of the neck to the sacrum and l_s is the number of bead surface. The coefficients in Eq. (4) were obtained through regression equations[10].

2.4. Three-dimensional calculation of curvatures of the spine

A curved image on the sagittal plane (*Y-Z*) was used to calculate the angles of kyphosis and lordosis. For this purpose, first a curve was fitted to the *M* points and after deriving from the curve, the position of the turning point was calculated. The angle of the curve between the seventh vertebra of the neck and the turning point determined the kyphosis angle and the angle of the curve between the turning point and the sacrum determined the lordosis angle. Similarly, for scoliosis anomaly, a curved image on the frontal plane (*X-Y*) was used and calculated after fitting the curve and derivation. The amount of beads rotation around the vertical axis is also calculated by the angle φ obtained in each horizontal sector.

3- Results and Discussion

The results of EOS imaging of the patient showed Cobb angle values on the frontal plane of 30.4 degrees in the chest area and 27.4 degrees in the lumbar area. In addition, the patient's kyphosis and lordosis angles were 70.3 and 50.2 degrees, respectively. Fig. 2 shows the curvatures of the patient's spine through surface data collection and analysis in the manner presented in this article.

4- Conclusions

In this study, surface data collection with depth gauge sensors was proposed as a completely non-invasive method for investigating spinal abnormalities. In this method, the curvature of the spine was estimated by analyzing the topographic map of the back surface without the need to mark the landmarks. One of the hypotheses of this study was the

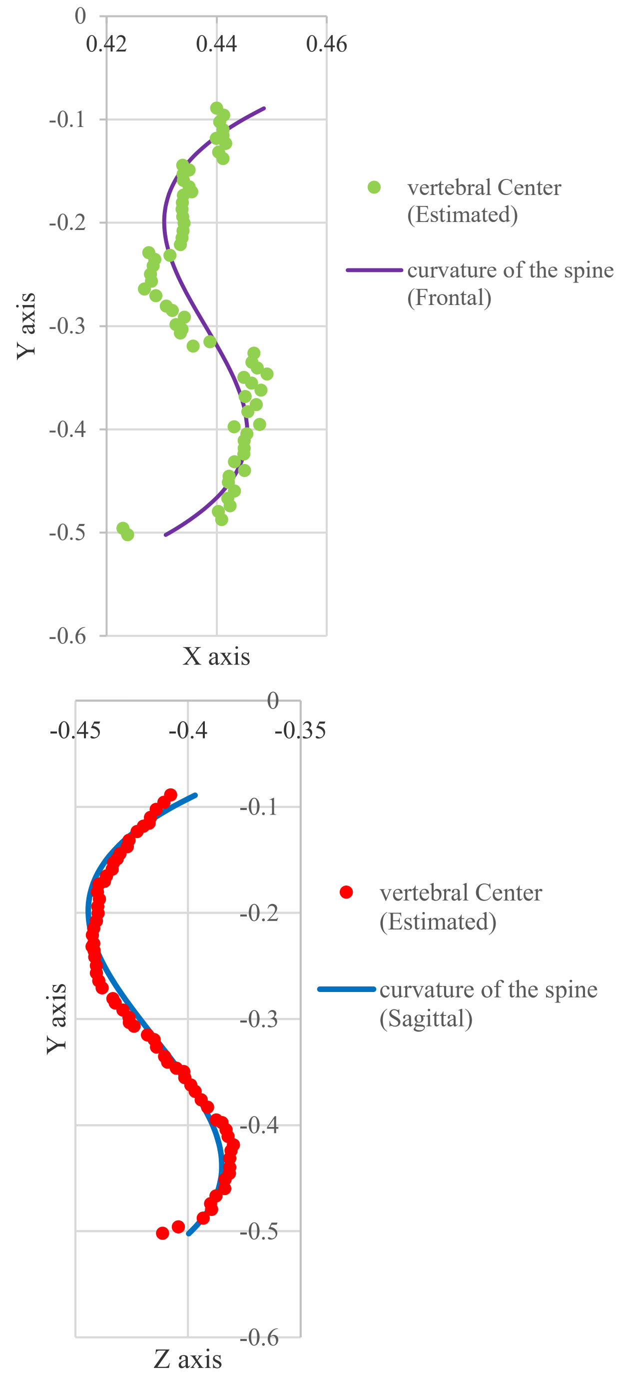

Fig. 2. Spinal curvature in the sagittal plane (down) and frontal (up) using surface data collection

location of the vertebral spinous process on the skin surface and in the minimum position of each cross section. Estimation of the rotation and length of beads from the normal surface vector and regression relationships were other limitations of this study, the accuracy of which will be evaluated in future studies by validity. If the results are confirmed, this safe and inexpensive method can be used as an alternative to radiography.

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