Measurement of 3D Model of Cobb's Angle on the Spinal Musculoskeletal Disorders

Sung-hoon Jeong, Sung-taek Chung, Sung-wook Shin

Abstract

The growth of industries has led to not only the improvement in quality of life but also increased musculoskeletal diseases due to accumulation of micro-sized damages in muscles or other tissues due to simple and repetitive lifestyle. Similarly, having curvature in the vertebrae is referred to as scoliosis, which is increasingly occurring mostly in teenagers. To diagnose such scoliosis easily, the patient was allowed to easily perceive about scoliosis by realizing a 3D backbone data through usage of the tilt sensor and encoder sensor. This is harmless to the human body compared to the expensive X-rays or MRI in addition to being possible to be mobile. The spinal curvature was made easily understandable by mapping the spinal data obtained through the devices that is proposed in this study into 3D modeling spinal image. By utilizing such image, Cobb’s angle was able to be easily obtained.

Keywords: Cobb’s angle, Musculoskeletal scoliosis, Tilt sensor, 3D modeling

1. Introduction

The today’s industrial growth has been generalized by the utilization of computers and automation of factories through which the quality of our lives has also been improved. Usage of computers is being utilized for hobbies, information search, games and other various purposes, and the working environment or the automation of production process is being completed without complicated process. Although such activities have minimized the movement of people and made work be possible with mere simple actions, musculoskeletal diseases due to overuse of bones, muscles or joints have increased [1-2].

Musculoskeletal diseases refer to diseases that show functional disability due to accumulated mechanical stress together with micro-sized damages in muscles or tissues caused by repetitive action, inappropriate working posture, usage of excessive force and others that leads to overuse of specific body parts and muscles. This most often occurs in the upper body parts such as the waist, neck, shoulders, arms, wrists and others where there are most repetitive actions being carried out [3].

The scoliosis, being one of the musculoskeletal diseases, signifies having morphological abnormality due to having spine that is bent either to the left or right. This is caused by having inappropriate posture for long time or environmental changes. The scoliosis can be categorized into nonstructural scoliosis wherein the spine is temporarily bent and structural scoliosis where in the spine is permanently bent, needing surgical therapy. In case of idiopathic scoliosis that belongs to the category of structural scoliosis, its cause is unknown and has characteristics of being gradually progressive and most often occurring in youths with fast growth. While it is important for idiopathic scoliosis to allow the patient to be corrected with rehabilitation and avoid needless surgeries through early discovery but most of the diagnoses are being performed by using expensive medical imaging equipments such as X-rays or MRI [4].

In this study, the spine curvature of the patient was allowed to be measured without being restricted by location while being harmless to the human body through 3D modeling of the spine image by using the measured spine data. For this, mobile spine data measuring device was developed and the spine curvature was modeled in 3D to easily obtain the Cobb’s angle.
2. Background

2.1 Musculoskeletal diseases

Although the term musculoskeletal disease is used in combination with terms such as cumulative trauma disorder (CTD), repetitive strain injury (RSI), occupational overuse syndrome (OOS) and visual display terminal (VDT) syndrome among others, it is recently being referred to as work-related musculoskeletal disorders (WMSDs) due to the increased work-related musculoskeletal disorders following the automation or mechanization in the working environment or production process.

Musculoskeletal disorders can cause pain in the neck area due to disc or accident, pain in the shoulders due to muscle damage or dislocation, pain in the back due to lumbar disc, scoliosis and others and pain in the knees due to arthritis and others, which are caused by various reasons such as working with same posture for long time, doing repetitive actions, performing strenuous actions, etc. In such cases, not only the daily lifestyle but also the working activities are affected and the purpose of the therapy becomes alleviation of pain due to the disorder instead of having full recovery of the disease.

Although this frequently occurred in shipbuilding and car manufacturing industries in the past, its occurrence is now gradually increasing in non-manufacturing industries such as medical or service industries due to the mechanization and automation of the working environment in accordance with the industry development. In addition, this is also occurring because of youths using the computer or studying with the same body posture for long time and also using heavy bags or bags that are carried on one side [5].

2.2 Musculoskeletal scoliosis

In musculoskeletal diseases, there is not only the scoliosis but also the lordosis in which the cervical and thoracic vertebrae is curved inwards towards the front of the body and also the cyphosis in which the curvature is in the opposite direction towards the back. In this study, the 3D modeling results on scoliosis with curvatures in both directions are explained.

![Figure 1. Comparison of curvature between (a) normal vertebrae and (b) scoliosis](image)

As shown in Figure 1, it can be observed that the vertebra is abnormally curved in scoliosis compared to normal spine. As observed in Figure 2, shoulders and the pelvis form a symmetry for normal spine but in case of scoliosis(Fig. 2(a)), the shoulders and the pelvis are not symmetric(Fig. 2(b)), which causes differences in leg lengths or changes in appearance such as one side of the back being raised when bending the back [6].

Scoliosis can be categorized into either nonstructural scoliosis, structural scoliosis or congenital scoliosis based on the causes. In case of nonstructural scoliosis, it is caused by incorrect posture and so the spine looks bent in the X-ray and there are differences between the pelvis or shoulder lengths and the leg lengths. However, such scoliosis is temporary and so it can be treated by correcting the causal habit by using straightening braces instead of surgical therapy.

Structural scoliosis is a type of scoliosis in which it gradually progresses together with growth wherein its signs of scoliosis appear visually or by X-ray as morphological changes in the vertebrae.
with causes most often unknown. The only way to treat this is to prevent further progress of the disease with early discovery or correct it by surgical means. In addition, structural scoliosis is also referred to as idiopathic scoliosis that takes up approximately 80~85% of all scoliosis and this progresses without special reason mostly during growth stage. This usually occurs around the age of 10 and the progress slows down after the growth stage. This occurs more frequently in female students than in male students.

\[ \text{Figure 2.} \text{ Comparison of symmetry from shoulders and pelvis between (a) normal subjects and (b) scoliosis patients} \]

It is referred to as congenital scoliosis when there is scoliosis due to congenital bone mutation, which takes up approximately 10~13% of all scoliosis patients. Aside from these scoliosis, there are also neuromuscular scoliosis due to malfunction of the vertebrae caused by nervous and muscular paralysis and neurofibroma scoliosis that occurs in neurofibroma patients [7-8].

2.3 Measuring method of scoliosis

\[ \text{Figure 3.} \text{ Comparison of Adam Test between (a) normal subject and (b) scoliosis patient} \]

It is very important for scoliosis to be discovered and treated early. Methods for checking for scoliosis include forward bending test (Adam Test) and X-ray to understand the presence of scoliosis or to observe the degree of scoliosis. The forward bending test is also referred to as the Adam Test and is a simple way to test for scoliosis. From an upright standing position as shown in Figure 3, the subject bends forward 90° after which equipment that can measure the height of both shoulders is used to check whether or not only one scapula is protruding in addition to checking for presence of difference in pelvic height to measure for scoliosis. X-ray imaging is a method that allows seeing the spine curvature right away and the
severity of the scoliosis can be measured through Cobb’s angle through which the degree of spine curvature can be understood.

![Figure 4. Method for measurement of Cobb's angle](image)

Figure 4 shows how to obtain the Cobb’s angle. The apex point at which the curvature is most severe becomes the base point and straight lines are drawn at start of curvature “Above apex” and end of curvature “Below apex”. For each of the straight lines, perpendicular lines that cross are drawn, which becomes the Cobb’s angle $\angle A$, which is equal to $\angle B$. Generally, it is diagnosed as scoliosis when the Cobb’s angle is 10° or higher. When the curvature is 40° or below, the progress of the disease can be prevented or be treated by correcting the lifestyle, posture or wearing of braces. However when the curvature is severe with angle higher than or equal to 40°, surgical therapy is needed since it may also damage the internal organs.

3. Experiment method

3.1 Composition of prepared measuring apparatus

In this study, a device for measuring the scoliosis with simple methods was prepared as shown in Figure 5 by using MCU (ATmega16), tilt sensor and encoder sensor. The tilt sensor is for measuring the left (X axis) and right (Y axis) tilt with maximum measurement range being ±30°. Because only left/right measurements are needed for scoliosis study, Y axis was not used.

The encoder sensor can convert the rotating angle of the rotating axis to electrical signal (pulse), which can measure the length of the vertebrae.

The system configuration of this equipment is show in Figure 6 The tilt sensor measures the left/right degree of bend of the spine and sends to MCU and the encoder sensor sends the signal (pulse) for constant period of counter. Then, the MCU sends an interrupt signal and sends the value of tilt sensor that is converted to ADC value to the PC in order to obtain the tilt and spine length values for the X and Y axis.

![Figure 5. Mobile musculoskeletal measuring device](image)
3.2 3D modeling of spine image

A real time data graph on the tilt sensor and encoder sensor values can be observed in Figure 7 in which the current state of the vertebra was modeled in 3D to obtain the Cobb’s angle.

The tilt sensor, which has range of ±30°, has ADC value of 100 when -30° and the ADC value increases by 13.7 for every increase of 1°, which gives ADC value of 920 at +30°. The ADC values of the tilt sensor were converted to tilt angle by using a converting equation like (1).

\[
\text{Tilt Angle} = \frac{\text{ADC} - \left(\frac{920 - 100}{2} + 100\right)}{13.7}
\]  

(1)

For 3D modeling of spine image, the coordinate values of the spine were first calculated. For the coordinate values of the spine, the unit vectors between the data were obtained by using the X, Y angles and the rotation matrix. The unit vectors were then accumulated to obtain the coordinate values. Also, the starting and finishing points for each were matched by using rotation conversion and scale conversion in order to directly map the 3D spine model and coordinate values of the spine.

\[
\vec{V}_{\text{m model}} = |\vec{P}_{\text{model end}} - \vec{P}_{\text{model start}} | \\
\vec{V}_{\text{real}} = |\vec{P}_{\text{real end}} - \vec{P}_{\text{real start}} | \\
\angle \theta = \cos^{-1} (\vec{V}_{\text{real}} \cdot \vec{V}_{\text{m model}})
\]  

(2)  

(3)  

(4)

In (2), the \(\vec{P}_{\text{model start}}\) and \(\vec{P}_{\text{model end}}\) are starting and finishing points in the 3D spine model whereas the \(\vec{P}_{\text{real start}}\) and \(\vec{P}_{\text{real end}}\) in (3) are the starting and ending points for the actually measured spine data. By using these, \(\vec{V}_{\text{m model}}\) and \(\vec{V}_{\text{real}}\) that are 3D spine model and actual spine model, respectively, were obtained. When the spine model vectors are inner product as shown in (4), the \(\angle \theta\) between the two vectors can be obtained. Also, rotation conversion is performed by rotating \(\angle \theta\) from plane of \(\vec{V}_{\text{m model}}\) and \(\vec{V}_{\text{real}}\).
In order to obtain the rotated results from the plane, upper vectors of the plane of $\mathbf{V}_{\text{real}}$ and $\mathbf{V}_{\text{model}}$ are obtained in case of $\mathbf{V}_{\text{plane}}$ of (5) and vertical and horizontal elements at $\mathbf{V}_{\text{plane}}$ are obtained by using the spine axial values ($\mathbf{V}_{\text{axial}}$). This can be expressed as vertical and horizontal elements in $\mathbf{V}_{\text{plane}}$ as shown in (6) and (7).

\[
\mathbf{V}_{\text{plane}} = \mathbf{V}_{\text{real}} \times \mathbf{V}_{\text{model}}
\]

(5)

\[
\mathbf{V}_{\text{vertical element}} = \mathbf{V}_{\text{plane}} \cdot \mathbf{V}_{\text{axial}}
\]

(6)

\[
\mathbf{V}_{\text{horizontal element}} = \mathbf{V}_{\text{axial}} - \mathbf{V}_{\text{vertical element}}
\]

(7)

$\mathbf{V}_{\text{vertical element}}$ in (8) is a vector that is perpendicular to $\mathbf{V}_{\text{horizontal element}}$ which is the horizontal element of $\mathbf{V}_{\text{axial}}$ while similarly also being a horizontal vector to $\mathbf{V}_{\text{plane}}$. Through this, if rotated by $\angle \theta$, the rotated data $\mathbf{V}_{\text{rotated}}$ as in (9) can be obtained. Because such spine model and spine axial values express different coordinate systems, they must be scaled through coordinate system conversion.

\[
\mathbf{V}_{\text{rotated}} = \mathbf{V}_{\text{horizontal element}} \cos(\angle \theta) + \mathbf{V}_{\text{vertical element}} \sin(\angle \theta) + \mathbf{V}_{\text{axial}}
\]

(9)

$\mathbf{R}_{\text{length}} = \sum_{k=1}^{n} R(k) - R(k-1)$

(10)

$\mathbf{M}_{\text{length}} = \sum_{k=1}^{n} M(k) - M(k-1)$

(11)

rate $= \frac{\mathbf{M}_{\text{length}}}{\mathbf{R}_{\text{length}}}$

(12)

$R_{\text{x}}(k) = (R(k) - R(K-1)) \text{rate} + R_{\text{x}}(k-1)$

(13)

$n$ in (10) and (11) stands for the total number of coordinate values while $k$ stands for the current number of coordinate values. Moreover, $R(k)$ or $M(k)$ is current position of the spine and spine model while $R_{\text{length}}$ is the total length of the spine, which is the sum of coordinate values of the spine. Also, $M_{\text{length}}$ in (11) is the total length of the model, which is the sum of model data. By using $R_{\text{length}}$ and $M_{\text{length}}$, the proportion between the two coordinate systems can be obtained as shown in (12) and when this is applied as shown in (13), the lengths of the spine and the 3D spine model would be equal.

3.3 Cobb’s angle calculation

As shown in Figure 4, Cobb’s Angle is obtaining either $\angle A$ or $\angle B$.

\[
X_{\text{max}} = \text{max}\{||R_{\text{x}}(j) \cdot \mathbf{V}(1,0,0)||\}
\]

(14)

\[
X_{\text{min}} = \text{min}\{||R_{\text{x}}(j) \cdot \mathbf{V}(1,0,0)||\}
\]

(15)

\[
X_{\text{mean}} = \frac{\sum_{k=1}^{n} R_{\text{x}}(k) \cdot \mathbf{V}(1,0,0)}{k}
\]

(16)
Apex = \begin{cases} \ell, & \text{if } |X_{\max} - X_{\text{mean}}| > |X_{\min} - X_{\text{mean}}| \\ \emptyset, & \text{otherwise} \end{cases} \tag{17}

When \( n \) is defined to be the last index data in the spine coordinates in the equations above, the indices from 0 to \( n \) in the coordinate list \( R_{\text{str}} \) are each shown as \( i, j \) and \( k \). Here, the “Apex” is the farthest point from the center, and so by obtaining the maximum value \( X_{\max} \) from the \( R_{\text{str}} \) coordinate list like in (14) and obtaining the minimum value \( X_{\min} \) like in (15), the index of the value that is further away from the average value \( X_{\text{mean}} \) of the list in (16) becomes the apex in (17). Therefore, the “Above apex” where the curve starts and the “Below apex” where the curve ends with the “Apex” as the base point can be obtained

\[
\overline{v}_{\text{up}}(\ell) = R_{\text{str}}(\ell - 1) - R_{\text{str}}(\ell), \quad \ell \leq \text{Apex} \tag{18}
\]

\[
\angle \theta_{\text{up}}(m) = \cos^{-1}(\overline{V}(1,0,1) \cdot \overline{v}_{\text{up}}(m)), \quad m \leq \text{Apex} \tag{19}
\]

Above apex = \{n, if \( \angle \theta_{\text{up}}(n) < \angle \theta_{\text{up}}(n + 1) \} \tag{20}

\[
\overline{v}_{\text{down}}(\ell) = R_{\text{str}}(\ell + 1) - R_{\text{str}}(\ell), \quad \ell \geq \text{Apex} \tag{21}
\]

\[
\angle \theta_{\text{down}}(m) = \cos^{-1}(\overline{V}(1,0,-1) \cdot \overline{v}_{\text{down}}(m)), \quad m \geq \text{Apex} \tag{22}
\]

Below apex = \{n, if \( \angle \theta_{\text{down}}(n) < \angle \theta_{\text{down}}(n - 1) \} \tag{23}

Because the \( \angle \theta \) value from the “Apex” to the “Above apex” or to the “Below apex” increases, \( \overline{v}_{\text{up}}(\ell) \) that is above the “Apex” is obtained by substituting index \( \ell \) that is less than or equal to the “Apex” into the \( R_{\text{str}} \) coordinate list. By using this, \( \angle \theta_{\text{up}}(m) \) can be obtained as shown in (19). As shown in (20), the point that decreases after comparing \( \angle \theta_{\text{up}}(n) \) and \( \angle \theta_{\text{up}}(n + 1) \) becomes the “Above apex” where the curvature begins. Likewise, “Below apex” can be obtained in similar method as shown in (21) and (22) by using index \( \ell \) that is higher than or equal to the “Apex”. The \( \angle B \) where the “Above apex” and “Below apex” obtained here crosses becomes the Cobb’s angle.

4. Experimental results

Because scoliosis is a disorder in which the spine curves to the left or to the right, the measurements are taken from the thoracic vertebra to the end of the lumbar vertebra as shown in Figure 8.

**Figure 8.** Direction and range of spine measurement

For the first experiment, the test was conducted by using an image with Cobb’s angle defined to be 43° in Figure 9.
Figure 9. Image with Cobb's angle defined

Figure 10 shows the results for the total of five measurements. The Cobb’s angle in these five cases were 43.49°, 42.26°, 41.66°, 43.19° and 42.27° with error of approximately 1.6%.

Figure 10. Measured angles and curve appearance through image

The second experiment was tested through image measured by the same X-ray as shown in Figure 11 and the Cobb’s angle was defined to be 18°.

Figure 11. X-ray image with Cobb's angle defined
The test was conducted in similar method as in the first experiment and the results of Cobb’s angle were 17.86°, 18.53°, 19.91°, 17.79° and 18.30° with error of approximately 1.4%.

5. Conclusion

In this study, spine data was easily obtained by using tilt sensor and encoder sensor, which as modeled into 3D image. Scoliosis is a musculoskeletal disorder that must be measured by X-ray or MRI. However, by obtaining Cobb’s angle through 3D image without being exposed to radiation or being restricted by location, early analysis of scoliosis can be conducted. As shown in the test results, the error was 1.6% and 1.4%, respectively, when experimenting with image that has Cobb’s angle defined. This presents that there is no difference with the Cobb’s angle obtained from existing equipments. However, there is a need to clinically prove this method since the test results in this study have not been obtained clinically.

Although this study was developed meant to only measure scoliosis, it is anticipated that spinal disorders can easily and simply be measured without exposure to radiation and restriction by location by realizing a method to measure lordosis (spine bending forward) and cyphosis (spine bending backward) as well in the future.

6. Acknowledgement

This research was supported by the MSIP(Ministry of Science, ICT&Future Planning), Korea, under the CITRC(Convergence Information Technology Research Center) support program (NIPA-2013-H0401-13-1006) supervised by the NIPA(National IT Industry Promotion Agency)

7. References