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Integrated Approach for Cobb Angle Estimation in X-Ray C-Curve Scoliosis Using Image Processing and Inverse Cosine Law

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Abstract: Cobb angle is the angle subtended by the most tilted vertebrae. It represents the degree of the spinal curvature and has been used to diagnose scoliosis. The severity of the scoliosis based on the cobb angle will determine the guide treatment and surgical planning. Manual measurement of Cobb angle using protractor or semi-manual using ONIS software is quite time consuming, and it is subjected to variations in interobserver and intraobserver measurements. This research proposed an algorithm to determine the Cobb angle using image processing and inverse cosine methods. The raw samples of X-ray images were obtained from Pusat Kesihatan Universiti (PKU), UTHM. Several interviews were conducted with radiologist at Pantai Hospital for verification purpose. Gaussian blur and unsharp mask were initially applied for noise removal in the preprocessing step. Three points were marked at the vertebrae image to assist for centroid estimation using Haar Cascade. The Cobb angle was estimated by applying the triangle formula derived from the inverse cosine law. In comparison to semi-manual method (Onis Software), the proposed technique has an error of less than 5 % and computes the Cobb angle 3.28 times quicker. In the future, it is suggested to explore other techniques such as deep learning for alternative data analysis for Cobb angle estimation.

Keywords: Scoliosis, Cobb angle, Haar Cascade, X-ray image, Onis software, Matlab

1. Introduction

Scoliosis is a three-dimensional structural abnormality of the spine commonly seen in 2 % to 4 % of the adolescent population, and 70 % to 80 % of the causes of scoliosis are not known with certainty [1]. It is a condition in which the spine has a sideways curvature. Scoliosis is most often diagnosed in children and adolescents. Scoliosis also can occur in certain people who are subjected to conditions such as cerebral palsy and muscular dystrophy. Most scoliosis cases are moderate. However, some curvature becomes worse as the children grow older. Significant scoliosis may be incapacitating. It may be more difficult for the lungs to work correctly if there is less space in the chest cavity due to a particularly severe spine bend.

Mild scoliosis in children is regularly evaluated to determine if the curve is worsening, typically via X-rays. Most of the time, no therapy is required. Some children will require bracers to prevent the curve from deteriorating. To correct extreme curvature, a surgery may be required [2]. The signs and symptoms of scoliosis can be detected by uneven shoulders, in which one shoulders blade appears more prominent than the other. Other symptoms are an uneven waist, and one side of the rib cage jutting forward. Based on the shape of the curve, scoliosis can be classified into two types, namely the C-curve and the S-curve [3]. Fig. 1 shows the normal spine compared to scoliosis patents' spine.

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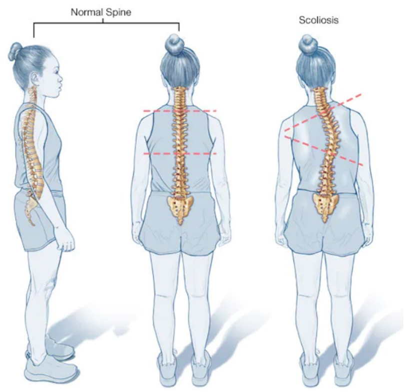


Fig. 1 - The normal spine compared to the scoliosis patient [2]

The degree of severity of scoliosis can be determined by measuring the Cobb angle [4]. It enables orthopaedic doctors to determine whether the patient's condition includes scoliosis. When the Cobb angle is greater than 10 degrees, lateral spinal curvature is referred to as scoliosis disease. Fig. 2 shows the how the Cobb angle can be determined. The upper vertebra (most tilted vertebra above the apex), apex, and lower vertebra (most tilted vertebrae below the apex) are the three main locations required when calculating the Cobb angle. The angle formed by the intersection perpendicular lines is known as the Cobb angle.

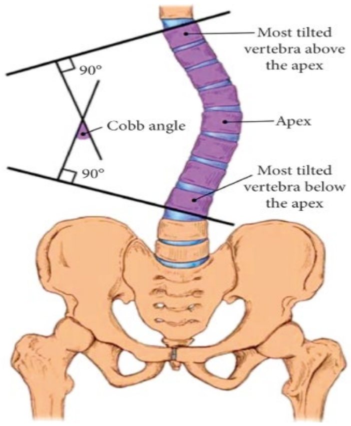


Fig. 2 - Method to determine the Cobb angle [5]

From previous research conducted by Maria Victoria et. al [6], they proposed a method for assessing scoliosis curvature using robotic ultrasound examinations. In their method, a robotic system was used to handle the ultrasound probe, which was manually positioned at the level of the sacrum to initiate the scanning procedure. The robot then monitored the movement of the spinous processes to trace the spinal curve. A disadvantage of this technique was the lack of a reference image of the subject's spine, although an X-ray image could be used to compare the scoliosis angle obtained by the robotic system [6]. Next, another study by L. Seoud and colleagues focused on predicting the type of scoliosis curve based on analysis of trunk surface topography [7]. The data acquisition procedure included an X-ray examination of spinal curves and expert clinical classification. However, this procedure was intrusive and did not consider the trunk's overall appearance, which is crucial for scoliosis assessment. Sinta Kusuma Wardani et al. proposed an image processing-based method for measuring spinal curvature in scoliosis classification. The system entailed loading the image, preprocessing it, segmenting it, and calculating the spine's distance curvature. This system's limitation was the absence of automatic segmentation optimization to increase accuracy [8]. Various methods were investigated in other studies, including FHIR-compliant applications for paediatric scoliosis patient rehabilitation [9], ultrasound volume projection imaging [10], optical methods for estimation and classification of idiopathic scoliosis [11], machine learning algorithms for early-stage scoliosis detection [12], and automatic extraction of skeletal maturity from scoliosis X-rays using convolutional neural networks [13].

In digital image processing applications, a variety of approaches are used to input images during the image pre-processing stage. It is because the chosen input images will contain a variety of sounds and undesired information, and the raw images gathered from the hospitals will not be suitable for processing directly. Therefore, preprocessing of the input photos is required before analysis. All medical imaging applications require image pre-processing as a requirement for additional processing like segmentation and classification [14]. Despite their size and location in the image, objects can be found in photographs using the Haar Cascade technique. This algorithm can operate in real-time and is not overly complex. The Haar Cascade detector can be trained to recognize a variety of items, including automobiles, bikes, structures, fruits, etc. The cascading window is used by Haar Cascade, which tries to compute features in each window and determine whether it might be an object. Meanwhile, to determine the Cobb angle, this research applied the use of trigonometry law based on the Law of Cosine. In Law of Cosine, the lengths of two sides and the measurement of the included angle are known as (SAS) and the lengths of all three sides known as (SSS), the remaining pieces of an oblique (non-right) triangle can be found using the Law of Cosines.

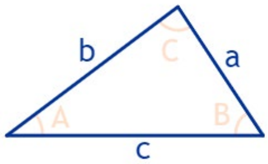


Fig. 3 - Three sides of triangle [15]

Fig. 3 shows the three sides of triangle and this figure will be used to describe the law of cosines. The law of cosines can be stated as:

$$c^2 = a^2 + b^2 - 2ab \cos C \tag{1}$$

With the exception of the third component, which equals zero if C is a straight angle and the Pythagorean Theorem results, this is similar to the Pythagorean Theorem. As a result, the Law of Cosines is a specific case of the Pythagorean Theorem [16]. Another way to express the Law of Cosines is:

$$b^2 = a^2 + c^2 - 2ab \cos B \tag{2}$$

$$a^2 = b^2 + c^2 - 2ab \cos A \tag{3}$$

To solve the three sides of the triangle, first can used the law of cosine to calculate one of the angles. Next, it's also can use the law of cosine to find the another angle.

$$\cos(C) = \frac{a^2 + b^2 - c^2}{2ab} \tag{4}$$

$$\cos(A) = \frac{b^2 + c^2 - a^2}{2ab} \tag{5}$$

$$\cos(B) = \frac{c^2 + a^2 - b^2}{2ab} \tag{6}$$

Traditionally, the radiologist will observe or check the curve of scoliosis patient by using a manual protractor on the laid X-ray film to get the Cobb angle. The inaccuracies of a standard protractor and large diameter marker on X-ray film contributed to the erroneous in Cobb angle [17]. Other method includes the use of transparent torsionometer (Perdriolle method) overlaid on the X-ray film. Nevertheless, this method is also subjected to inaccuracies of measurement. Previous research implemented the use of image processing to determine scoliosis was by using Sum of Squared Difference (SSD) to define the curvature [17]. The SSD was calculated as a summation of the squared for the pixel's subtraction between template and source window. As a result, the equation to get the X-direction and Y-direction was obtained for estimating scoliosis at X-ray image [17]. The capability of image processing technique to assist in determining the Cobb angle has driven the motivation for this project. This research proposed the use of image processing and trigonometry law methods to detect the Cobb angle of C-curve scoliosis based on X-ray images. Nowadays, the technologies to find the Cobb angle on an X-ray image is very expensive and this advanced system is mostly available in private hospitals. Therefore, this project offers an alternative low cost and simple approach to detect the Cobb angle for scoliosis patient through the use of image processing and inverse cosine methods.

Based on the problem statement, the aim of this research is to estimate the Cobb angle of C-curve scoliosis X-ray image by using image processing techniques and inverse cosine law. Three objectives were formulated which are to detect three points of upper vertebrae, apex, and lower vertebrae for centroid estimation using image processing techniques, to determine the Cobb angle based on inverse cosine and finally, to evaluate the proposed image processing solution by comparing with the semi-manual method. Meanwhile, for the scopes of this research only C-curve scoliosis was chosen as the image sample. A collaboration with Pusat Kesihatan Universiti, Universiti Tun Hussein Onn Malaysia (PKU UTHM) was initiated, and the X-ray images were acquired from them. Next was to investigate suitable image processing techniques that can be used to determine the positions of upper vertebrae, apex, and lower vertebrae. Then, the formula of triangle method was implemented to assist the estimation of the Cobb angle. As for the validation purpose, the proposed method was compared to the semi-manual method (ONIS software) with the results validated by the radiologist expert.

2. Methodology

This section presents the development of algorithm to estimate the Cobb Angle for C-curve scoliosis. Fig. 4 shows the key processes for the execution of this project. Briefly, the sample of images were obtained from the PKU, UTHM. Then, a few interview sessions with radiologist in Pantai Hospital were set to get a deeper understanding on the use of Onis software as well as to obtain the expert verification for the Cobb angle of the collected samples of X-ray images. Next step involved the development of the algorithm in which several image processing techniques were investigated, and the most suitable techniques were selected. Then, a technique known as inverse cosine law was implemented to find the Cobb angle. Finally, the developed algorithm was tested and evaluated based on error calculations and the time taken to process the Cobb angle.

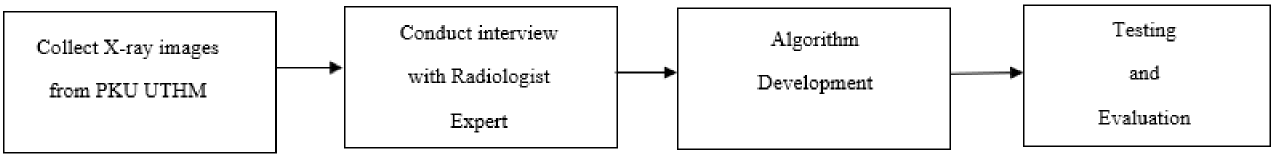


Fig. 4 - The key process of the project

2.1 Findings from Interview with Radiologist

Several interview sessions were carried out with radiologist specialist at Pantai Hospital for verification purpose. In this research, the radiologist helped to verify the Cobb angle of X-ray images samples by using Onis software. In Onis software, two lines are drawn at two selected points namely upper vertebrae (the most-tilted vertebrae above the apex), and lower vertebrae (the most-tilted vertebra below the apex). After that, the radiologist will have to use a ruler to draw two long perpendicular lines extending from the upper and lower vertebrae until both lines were intersected to enable the Cobb angle reading. As a result, the Onis software will automatically display the Cobb angle value when both perpendicular lines intersect. Fig. 5 shows an example of the Cobb angle (21.32 degree) verified by the radiologist using Onis software.

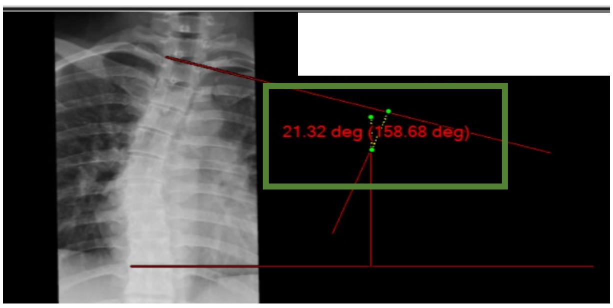


Fig. 5 - Semi-manual detection of Cobb Angle using Onis software

2.2 Algorithm Development

The coding for estimation of the spinal curve was coded in MATLAB software. Fig. 6 shows the proposed algorithm process for this project. The X-ray image was processed in a greyscale form. In the preprocessing step, the Gaussian blur and unsharp mask were applied to remove any unwanted images. Then, the vertebrae image was manually cropped to get the region of interest. Three points were marked at the vertebrae for determination of centroid estimation using Haar Cascade. These three points represents the apex vertebra, which is at the deepest part of the scoliosis curve, follows by the most-tilted vertebra above the apex and the last one is the most-tilted vertebra below the apex. Next, the Cobb angle was defined using the inverse cosine algorithm.

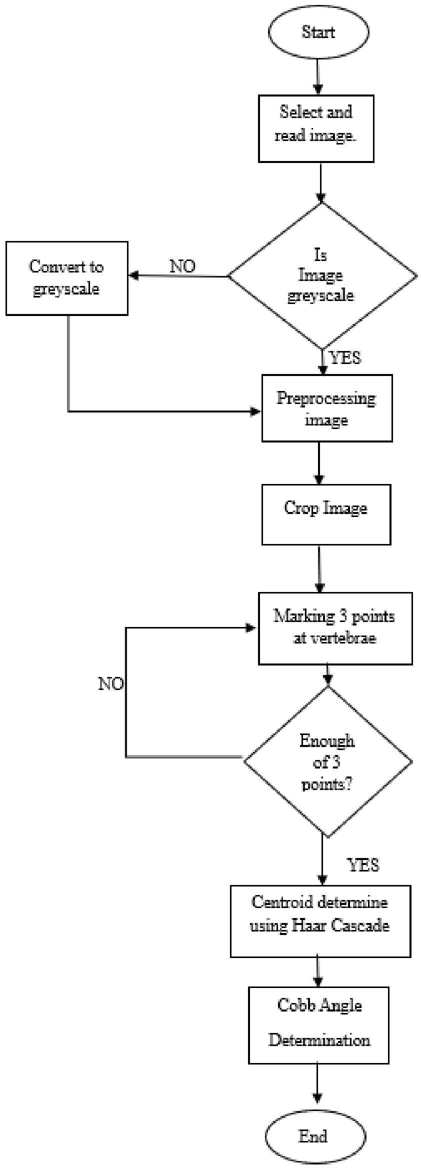


Fig. 6 - The flowchart of proposed algorithm

This research used the definitions in equation 4 to get the accurate Cobb angle. Fig. 7 shows an alternative representation of how the Cobb angle, γ can be determined. Assume A is the upper coordinate *(x1, y1*) represents the most-tilted vertebrae above the apex, B is the lower coordinate (*x2, y2*) represents the most-tilted vertebrae below the apex whereas C is the apex vertebrae coordinate (*x3, y3*). Meanwhile, *a*, *b* and *c* represent the length between point B and C, point C and A and point B and A, respectively. Then, the written coding measures the length of each side (*a*, *b* and *c*) based on equations 7 until 9. Finally, the Cobb angle is computed based on equation 10.

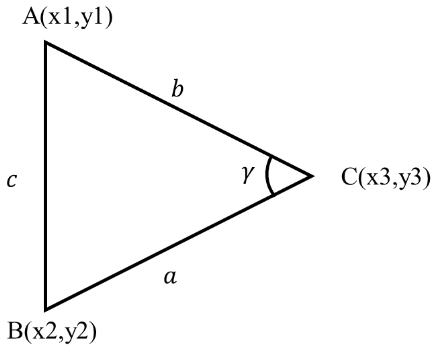


Fig. 7 - Application of triangle formula to obtain Cobb Angle, γ

$$a = \sqrt{(x1 - x2)^2 - (y1 - y2)^2} \quad (7)$$

$$b = \sqrt{(x2 - x3)^2 - (y2 - y3)^2} \quad (8)$$

$$c = \sqrt{(x3 - x1)^2 - (y3 - y1)^2} \quad (9)$$

$$\gamma = \arccos\left(\frac{a^2 + b^2 - c^2}{2ab}\right) \quad (10)$$

2.3 Testing and Evaluation

To evaluate the performance of the developed Cobb angle estimation, a comparison analysis based on error percentage was conducted in this study. The formula to calculate the percentage error is:

$$Percentage\ Error = \left|\frac{V_{observed} - V_{true}}{V_{true}}\right| \times 100 \quad (11)$$

where $V_{observed}$ is the Cobb angle value determined from the proposed algorithm whereas V_{true} is the Cobb angle from Onis verified by radiologist. Then, the second evaluation is based on the time taken to obtain the Cobb angle using the proposed technique and Onis software. A stopwatch was used to measure the time in second. To calculate the ratio of time taken, the formula used is as follows:

$$Ratio = \frac{Time\ taken\ using\ Onis\ software}{Time\ taken\ using\ proposed\ method} \quad (12)$$

3. Results and Discussion

This section consists of the main results, analysis, and discussion on the developed system to detect the Cobb angle.

3.1 Marking Three Points

Fig. 8 shows the resulted three points marked on the vertebrae for sample image of Subject #1. These three points indicate the upper vertebrae, apex, and lower vertebrae. To reduce the error, the technique to mark the points must follow the same point when marking using semi-manual (Onis software) technique.

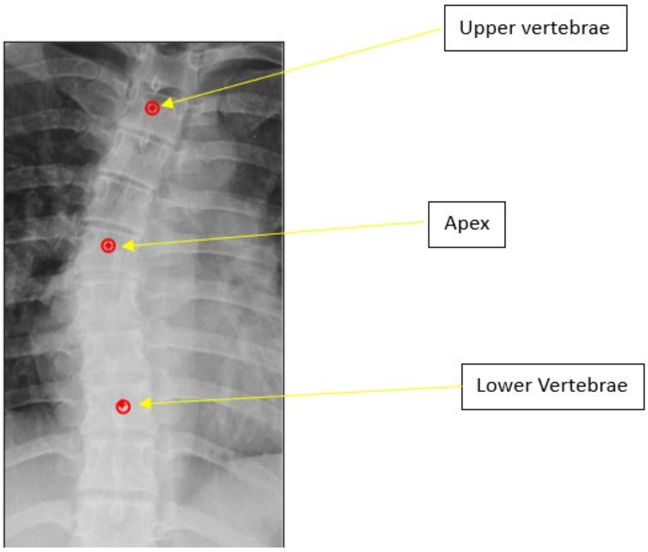
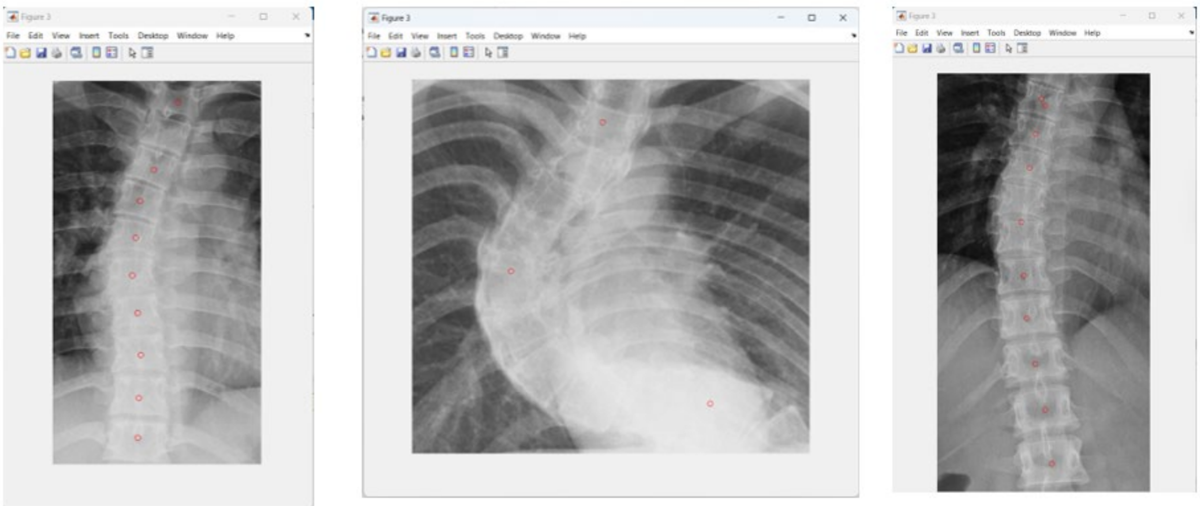


Fig. 8 - X-ray image with marking points at three main locations

3.2 Centroid Estimation Using Haar Cascade and Cobb Angle Estimation

The outcomes of centroid estimation using Haar Cascade is shown in Fig. 9. Numerous points of centroid estimation may be seen in the X-ray image of Subject #1 and Subject #4. On the other hand, the resulted image of Subject #2 (Fig. 9(b)) only shows three centroid estimation locations. This is probably because the second subject has overly curved bones and this affected the capability of Haar Cascade when detecting the bones pixels. Meanwhile, Fig. 10 shows the snapshot example of Cobb angle reading for Subject #1 as appears at the end of the coding.



(a) (b) (c)

Fig. 9 - (a) Centroid estimation for (a) Subject #1; (b) Subject #2, and; (c) Subject #4

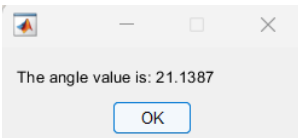


Fig. 10 - Cobb angle reading obtained for Subject #1

Meanwhile, Table 1 shows the resulted of average Cobb angle calculated from the inverse cosine law. It can be seen that Subject #2 has the highest Cobb angle since the vertebrae was overly curved whereas Subject #5 has the lowest Cobb angle. Further analysis on the error percentage was calculated as depicted in Table 2 by comparing the proposed method with the semi-manual method. It should be highlighted here that the results from Onis software were successfully verified by the radiologist expert. Comparing the proposed method with the semi-manual method, all resulted Cobb angles were having less than 5% of error and these results considered acceptable. Meanwhile, Table 3 shows the analysis of processing time to obtain the Cobb angle. Using equation (12), the proposed method was found to be 3.28 faster than the Onis software when computing the Cobb Angle.

Table 1 - The average Cobb angle reading computed using inverse cosine law

Methods	Subject	Reading 1	Reading 2	Reading 3	Average
Proposed technique	1	21.63	21.14	21.46	21.41
	2	56.31	54.37	57.60	56.09
	3	12.10	12.32	11.68	12.03
	4	19.94	19.24	18.68	19.28
	5	13.73	12.06	14.26	13.35

Table 2 - Percentage error between proposed method and Onis Software in determining the Cobb angle

Subject	Cobb angle (°)		% Error
	Method: Semi-manual (Onis Software)	Method: Proposed Technique	
1	21.32	21.41	0.4
2	54.73	56.09	2.5
3	11.61	12.03	3.6
4	19.51	19.28	1.2
5	13.87	13.35	3.7

Table 3 - Analysis of processing time

Subject	Time taken to obtain cobb angle (second)		Ratio of time taken
	Method: Semi-manual (Onis Software)	Method: Proposed Technique	
1	84	22	3.8
2	94	31	3.0
3	82	21	3.9
4	80	28	2.9
5	79	28	2.8
		Average	**3.28**

4. Conclusion

In conclusion, all objectives of this project were successfully achieved. The process of this project involving pre-processing step, marking point, centroid estimation, and finally calculation of Cobb angle. The region of interest of spinal's thoracic and lumbar segment in scoliosis patient c-type curve were accomplished by manually cropping the interest part. Three main points (upper vertebrae, apex, and lower vertebrae) were selected, and the centroid estimation was determined via Haar Cascade. Based on the resulted centroid estimation, the lengths of the triangle sides of the three selected points were calculated. Finally, the Cobb angle was then determined by using the inverse cosine formula. The proposed technique was evaluated by comparing with the semi-manual method using error analysis and time taken to obtain the Cobb angle. The percentage error achieved less than five percent whereas the average time ratio to obtain the Cobb angle using proposed technique is 3.28 faster than the semi-manual method (Onis software).

As for recommendation, an implementation of deep learning to determine the Cobb angle can be suggested. However, there is a limitation in which the sample images are very difficult to obtain. For example, due to the limit resources to obtain the sample, this study only used five samples of X-ray images of the scoliosis C-curve patient provided by PKU, UTHM.

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