An Innovative Approach for Assessing Adolescent Idiopathic Scoliosis through the Use of a Stewart Platform and Stereo Vision Technology

*X. Zheng1), S.K. Ong2) and A.Y.C. Nee3)

1), 2), 3) Department of Mechanical Engineering, National University of Singapore
Engineering Drive 1, 117576, Singapore
1) zheng_xin@nus.edu.sg

ABSTRACT

Medical robots have been applied to a variety of areas and have great potential to radically change the mode of surgical operations and conventional medical-care as part of a more information-intensive environment that exploits the complementary strengths of computer-based technology.

Scoliosis is an unnatural curvature or deformity of the spine with lateral deviations from the normally vertical spinal outline. As one of the most common occurrence, if left undetected and untreated, adolescent idiopathic scoliosis can impact the quality of life during the period of rapid body growth, leading to a disturbed self-image, potential back pain, and pulmonary and cardiac problems in later life. This paper develops an innovative and integrative system consisting of a Stewart Platform, which is a type of parallel kinematic motion manipulator, to assist scoliosis measurement. Using this system, a subject’s bending posture can be obtained with high repeatability in a series of pre-defined angles, e.g., 0°, 30°, 45°, and 90°. For each posture, images of the subject’s back can be captured using stereo cameras and analyzed quantitatively to determine the presence and severity of scoliosis. Furthermore, all the data are stored in the database for further monitoring and assessment.

By introducing information-driven assessment tools, this research helps doctors and surgeons to treat individual patients with greater safety, improved efficacy, and reduced morbidity in the measurement of scoliosis.

KEYWORDS: Robot-assisted system, Spinal deformity measurement, Stewart Platform, 3D Spinal shape generation

1. INTRODUCTION

Medical robotic systems have the ability to couple complex information to physical actions to perform useful tasks and have a potential to fundamentally change the surgical and interventional medicine as part of a broader, information-intensive environment that exploits the complementary strengths of humans and computer-
Adolescent idiopathic scoliosis (AIS) is a long-term spine disease that influences approximately 3% to 5% of children in the at-risk age from 10-16 years old. Different groups have different definitions of scoliosis, which are usually specified as > 10 degrees lateral curvature of the spine, as measured using the benchmark Cobb angle method, typically accompanied by vertebra rotation (Scoliosis Research Society Glossary 2008 and Reamy 1983). Presently, the pathogenesis and etiology of this spinal deformity still remains unrecognized although it is considered to be a multi-gene dominant case with variable phenotypic expression. Nowadays, it is a popular research topic as increasingly more researchers and clinical doctors have committed to spine scoliosis rehabilitation. A serious three-dimensional deformity of the spine will affect the appearance and the quality of life during a person’s growing period, leading to a self-abased image, potential waist and back pain, and cardiac complication in later life. In general, the most common symptom of the AIS condition can be the back shape in the form of a letter “S” or “C” shapes as described in the King classification system (King 1983). A number of scientists reported that AIS is one of the most epidemic musculoskeletal diseases affecting children (Narayanan 2008) because of the vertebral rotation and deformity resulting in rib cage and flank muscle asymmetries (Weinstein, 2008).

Screening programs for AIS have been conducted for many years in some countries. In the pre-inspection for scoliosis for teenager students in schools, experienced orthopedic doctors conduct physical examination for paediatric spinal deformity to diagnose if the students need to be referred to hospitals or clinics for further treatment. In assessing the scoliosis level, the Adams forward bending is popularly used in school scoliosis screenings. Since 1970’s, this method has been one of the most prevalent techniques in the back-shape analysis process to identify spinal deformity in school-age pupils (Pearsall 1992, Fairbank 2004, Adair 1977, Windischbauer 1995, Ruggerone 1986 and Sahlstrand 1986). Although extensive research works on scoliosis measurement and treatment have been investigated in the last few decades, there is still room for the development of measurement techniques as according to the previous research, the forward bending test suffers from the problems of reliability and effectiveness, especially when it is used as the sole screening and diagnosis method.

The traditional method for assessing scoliosis is the Cobb angle parameter. A 2D radiograph of the spine is made in the coronal plane and the angle of the spinal curve, which is referred to as the Cobb angle, is measured. A treatment decision is made by the doctor based on this Cobb angle. There are several disadvantages; firstly, scoliosis is a three-dimensional deformity of the spine while the radiographic Cobb angle measurement only provides two-dimensional information, which makes this method potentially inaccurate (Stokes 1989). In order to track the progress of the spinal deformity, the patients have to undergo routine radiographs, which could lead to potential radiation induced diseases or genetic mutation due to the X-ray exposure (Levy 1996).

In order to reduce X-ray exposure and diagnosis cost, a medical-robot-supported system is a potential application in scoliosis measurement. Some innovative systems
and methods have been applied in the hospital and research laboratories, such as the easy-to-use handheld devices including body contour tracers (Pearsall 1992 and Pun 1987), scoliometer (Bunnell 1984) and spinal rotation meter (Pruijs 1995). Moiré fringe topography has been applied since the 1970’s as an alternative method to the Adams forward bend test in school scoliosis screening (Adair 1977). However, some researchers argued that Moiré fringe topography is unreliable as a clinical measuring device (Ruggerone 1986 and Sahlstrand 1986) because of the complexity of analyzing the resulting fringe patterns with the random influence from the patients’ movement and posture. In 1980s, some laboratories and hospitals managed to apply the raster stereographic techniques system and analyze the resulting patterns in direct relationship with the three-dimensional shape of the patient’s back for efficient treatment decision making (Thometz 2000). Up to now, the most popular measurement systems include the Formetric3D/4d system (Goh 1999), the Quantec system (Thometz 2000), the Integrated Shape Imaging System (ISIS) (Turner-Smith 1998), and a newly-developed updated ISIS method (ISIS 2) using organized lights and Fourier transform profilometry technology (Berryman 2008). However, these methods are not commercially available and widely accepted because they need large preparation time, but remain helpful for school screening programs.

To measure the deformity of the spine, a customized testing apparatus is usually used, such as the stadiometer which has been described to be bulky, non-portable, and uncomfortable for mass testing purposes. This device is commonly used in research laboratories and clinics, but it only measures the linear spinal deformity and changes in spinal segments in the standing position (Stothart 2000 and Kourtis 2004).

The objective of this research is to build a safe non-contact and radiation-free system to measure human spine deformity using Stewart Platform, which is a parallel robot, and computer vision technique. In this study, an innovative and integrative system consisting of a Stewart Platform, a controllable mechanical apparatus and a motion capture camera system is proposed. The advantages of implementing computer vision technique are that it is a non-invasive method and it can provide high accuracy and efficiency. By capturing information of the positions of the spine prominence, this system could generate virtual 3D clinical records for subsequent re-measurement.

The remainder of this paper is organized as follows. The methodology and algorithms are introduced in Section 2. The implementation of the mechanical apparatus and the imaging system are presented in Section 2. Preliminary experiments and results are explained in Section 3. In Section 4, extensive discussion on the application of the system and future work design are presented.

2. METHODOLOGY AND ALGORITHM

2.1 Design of the Stewart Platform-Stereo Vision Integrated System

In the diagnosis and measurement methods commonly used for scoliosis, such as the Adam forward bending method or the X-ray radiography detection, the patient is usually in a static state or posture (Fairbank 2004). As the patient moves, such as bending forward, the human back and spine shape may present a relatively different
topology. If the subject changes from a standing position to a bending forward position with dangling arms, the spinal curvature due to scoliosis may become more distinct and can display different patterns.

This research proposes an integrated system consisting of a Stewart Platform, a mechanical frame for supporting a subject and image processing equipment. An expert system for the measurement, storage and interpretation of the data of the human spinal deformity to achieve rapid examination of a large amount of medical data will be developed. This measurement system combines the advantages of the manoeuvrability of the Stewart Platform, medical examination methods and computer vision technology, and eliminates the hazard of x-ray radiation.
In this research, the subject's posture can be controlled by a specially-designed Stewart Platform. The subject stands in front of the platform, holds the handles on the side of the apparatus and leans onto the moveable plate of the platform. The platform is designed to achieve different bending movements to generate different bending angles accurately.

A commercial stereo camera system is used in this research for capturing the shape of subject's spine. The motion capturing system consists of three OptiTrack cameras and several round reflective markers to obtain the trajectory of the human spine. The markers are made from reflective material that can be tracked by the camera easily, and they are attached to the prominence points of human spine. To track the markers, three OptiTrack cameras are arranged to have overlapping fields of view. For the best calibration and tracking results, the cameras should be placed at different positions and heights so that they face the target region from different angles. This creates an area called the capture volume in which tracking can occur. A schematic illustration of the system is shown in Fig. 1. The architecture design for the spinal deformity measurement system is shown in Fig. 2.

Before the spinal measurement process starts, the Stewart Platform (SP) and the camera system are set up with trial movements of the SP to ensure its smooth running. The SP and the camera system are calibrated to improve the accuracy of the SP operation and the image-capturing process. Several round reflective markers are attached onto the prominence points of the subject's bare back. The system is activated to bend the subject forward in a series of angles of 0°, 30°, 45°, 60°, and 90° using the precise movement of the SP. An angle of 0° means that the subject is standing upright and an angle of 90° means the subject is almost lying flat onto the mechanical frame. However, the current setup cannot achieve a 90° bend due to the constraint imposed by the linkages. For each bending angle and the corresponding posture of the subject, the back image is captured through the reflective markers. For each image captured, the position and orientation of the reflective markers are identified to indicate the spinal prominence. The spine shape and the degree of spinal deformity are obtained by analyzing the positions and orientations of the markers. Finally, all the data are stored in the subject's database which can be analysed and plotted for monitoring the deformity changes.

### 2.2 Design and Construction of the System

In this research, the components of the human spine deformity measurement system include the Stewart Platform, a mechanical frame, OptiTrack stereo vision cameras and image processing tools. The posture of the subject is controlled using the Stewart Platform and the mechanical frame which is activated by the SP. They are described as follows.

(a) **Stewart Platform.**

The Stewart Platform consists of sets of independently designed modules, such as the fixed base plate, mobile plate, passive joints, rigid links and actuators. Fig. 3 shows the structure of the Stewart Platform and Fig. 4 shows the components and final construction of the platform.
(b) **Mechanical Frame.**

The mechanical frame is used to transfer the horizontal movement of the SP to the rotation movement of the moveable frame about the hinge to guide the subject into a series of bend angles. The frame is designed to support the subject’s weight when he/she leans forward against the moveable plate while the measurement is in process. The construction of the mechanical frame is shown is Fig. 5. The frame is a detachable part assembled using aluminium bars and two universal joints.
In the design of the measurement system, stereo vision cameras and reflective markers are used to identify the 3D position and orientation of each vertebra. Three OptiTrack V100:R2 cameras from NaturalPoint Inc. (OptiTrack camera website) are used in this system to capture the subject’s back topology. This system could offer integrated image capturing, data processing, and motion tracking in a compact package (Rodacki 2001). Specially-designed round markers are used with the 3D cameras for spine deformity measurement. Fig. 6 (a) shows the configuration of the OptiTrack cameras used in the system and Fig. 6 (b) shows the 7/16 inch diameter round markers which are made from reflective materials with mounting holes.

In this research, the subject’s posture is controlled by the specially designed equipment described above. The subject stands in front of the platform, holds the handles on each side and leans against the moveable plate which is designed to achieve the bending movement and generate the bending angles accurately. By
operating the platform, the subject can bend his or her waist in precise angles. The schematic of the apparatus is shown in Fig. 7.

The movement of the frame is controlled using the Stewart Platform, which is a six-leg parallel kinematic manipulator. The six legs are controlled and activated by individual actuators such that the top plate can achieve six degrees of freedom (DOF), namely, the three linear movements along the x-, y-, and z-axis (lateral, longitudinal and vertical) and the three rotational movements (pitch, roll and yaw). The specially-designed frame which is connected to the mobile plate of the Stewart Platform can be
activated, allowing the subject’s body to bend forward. As the Stewart Platform moves, the frame is manipulated to rotate about the hinge such that the intersection angle between the moveable frame and the horizontal plane can be controlled accurately as shown in Fig. 8.

3. MEASUREMENT AND EXPERIMENT RESULTS

3.1 Subject Preparation for the Imaging

Prior to carrying out the measurements, consent will be obtained from the subjects. During the measurement, the spine is labelled with round reflective markers as shown in Fig. 9. These markers are attached at several prominent positions of the back corresponding to the locations of the vertebrae according to the following anthropometric points: superior spinous processes of T1, T3, T6, T9, L1, L3 and L5 and both posterior superior iliac spines (PSIS).

![Fig. 9 The mechanical frame and the anthropometric marking position on vertebrae](image)

3.2 Calibration of the 3D Camera System

The Stewart Platform and the imaging system are assembled using modular aluminium sections, universal joints and linkages. Three cameras are set up two meters away from the subject in a triangular layout. Before the measurement, calibration is performed. The OptiWand and the self-calibration function in the program are used for the system calibration. The OptiWand is moved back and forth several times in the overlapped region of the three cameras. The three 3D cameras can track the trajectories of the OptiWand to identify the real position of the cameras.

After calibration, the system can adjust the virtual camera position by tracking the position of the markers. The direction and orientation of the virtual camera can also be
changed to top and side views to observe the subject. The trajectory and position of the markers can be detected accurately.

3.3 Imaging Process with the Subject

During the imaging process, the subject stands in front of and as close as possible to the frame to establish the necessary reference. The subject is requested to take several deep breaths. Fig. 10(a) shows the setup of the custom-built aluminum frame and the cameras and Fig. 10(b) shows the standing position of the subject.

The markers can be selected in the program and are created as trackable objects. The markers on the prominent points of the subject’s back in this arrangement are considered as a rigid body presenting the shape of the spine. The benefit of establishing a rigid body using the collection of markers is that the program can provide the position and orientation of the rigid body. Therefore, the spine shape and trunk deformity can be expressed by the position and orientation of the markers. Fig. 11 shows the interface of the imaging program and the position and orientation of the rigid body of the spine. The default point clouds of the markers are circles in white color.

![Fig. 10 (a) the setup of the aluminum frame; (b) the standing position of the subject during measurement](image)

![Fig. 11 The interface of the imaging program and the position and orientation of the trackable markers](image)
The program is designed to perform semi-automated offline measurements. The x, y and z coordinates and roll, pitch, yaw rotation matrices of the points of interest can be obtained. Fig. 12 (a) shows the results of the digitizing process of the markers. The distance between every two markers is calculated, which is shown in Fig. 12(b).

![Fig. 12 (a) the result of digitizing process of the markers; (b) the calculation of the distance between every two markers](image)

### 3.4 Result Analysis and Discussion

As the frame bends forwards, the subject also bends following its movement. The coordinates and orientation of each maker are obtained by the image capturing process using the three cameras.

![Fig. 13 (a) the process of the measurement when the subject bends 0°; (b) the spine shape of the subject in 0°](image)

- **Bending 0°**.
  Fig. 13(a) shows the measurement process when the subject is upright (bends 0°) and Fig. 13(b), the spine shape on the right. Table 1 presents the coordinates of each marker obtained from the program.
Table 1 Results of the coordinates of the each marker

<table>
<thead>
<tr>
<th>Bending 0°</th>
<th>X</th>
<th>Y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marker 1</td>
<td>0.094939</td>
<td>0.421405</td>
<td>0.009160</td>
</tr>
<tr>
<td>Marker 2</td>
<td>0.095374</td>
<td>0.294062</td>
<td>0.060063</td>
</tr>
<tr>
<td>Marker 3</td>
<td>0.090049</td>
<td>0.174936</td>
<td>0.091595</td>
</tr>
<tr>
<td>Marker 4</td>
<td>0.080009</td>
<td>0.054471</td>
<td>0.090919</td>
</tr>
<tr>
<td>Marker 5</td>
<td>0.074024</td>
<td>-0.069586</td>
<td>0.079346</td>
</tr>
<tr>
<td>Marker 6</td>
<td>0.063718</td>
<td>-0.168669</td>
<td>0.083874</td>
</tr>
<tr>
<td>Marker 7</td>
<td>0.166565</td>
<td>-0.263104</td>
<td>0.107102</td>
</tr>
<tr>
<td>Marker 8</td>
<td>-0.038108</td>
<td>-0.248970</td>
<td>0.113797</td>
</tr>
</tbody>
</table>

Fig. 14 (a) the process of the measurement when the subject bends 30°; (b) the spine shape on the right. Table 2 presents the coordinates of markers obtained from the program when the subject bends 30°.

Table 2 Results of the coordinates of the each marker

<table>
<thead>
<tr>
<th>Bending 30°</th>
<th>X</th>
<th>Y</th>
<th>z</th>
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<tr>
<td>Marker 1</td>
<td>0.068403</td>
<td>0.161819</td>
<td>-0.601594</td>
</tr>
<tr>
<td>Marker 2</td>
<td>0.074732</td>
<td>0.108717</td>
<td>-0.484345</td>
</tr>
<tr>
<td>Marker 3</td>
<td>0.080169</td>
<td>0.061720</td>
<td>-0.381699</td>
</tr>
<tr>
<td>Marker 4</td>
<td>0.080480</td>
<td>0.004158</td>
<td>-0.292391</td>
</tr>
<tr>
<td>Marker 5</td>
<td>0.087523</td>
<td>-0.060514</td>
<td>-0.179107</td>
</tr>
<tr>
<td>Marker 6</td>
<td>0.080508</td>
<td>-0.143370</td>
<td>-0.080063</td>
</tr>
<tr>
<td>Marker 7</td>
<td>0.193752</td>
<td>-0.243630</td>
<td>0.011146</td>
</tr>
<tr>
<td>Marker 8</td>
<td>-0.013793</td>
<td>-0.223346</td>
<td>0.024004</td>
</tr>
</tbody>
</table>

- **Bending 30°**.
  Fig. 14(a) shows the process of the measurement when the subject bends 30° and Fig. 14(b), the spine shape on the right. Table 2 presents the coordinates of markers obtained from the program when the subject bends 30°.

- **Bending 45°**.
  Fig. 15(a) shows the process of the measurement when the subject bends 45° and Fig. 15(b) the spine shape on the right. Table 3 presents the coordinates of markers obtained from the program when the subject bends 45°.
Fig. 15 (a) the process of the measurement when the subject bends 45°; (b) the spine shape of the subject in 45°

<table>
<thead>
<tr>
<th>Bending 45°</th>
<th>X</th>
<th>Y</th>
<th>z</th>
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</thead>
<tbody>
<tr>
<td>Marker 1</td>
<td>0.127031</td>
<td>0.320028</td>
<td>-0.336520</td>
</tr>
<tr>
<td>Marker 2</td>
<td>0.100844</td>
<td>0.247435</td>
<td>-0.257044</td>
</tr>
<tr>
<td>Marker 3</td>
<td>0.096583</td>
<td>0.152957</td>
<td>-0.184070</td>
</tr>
<tr>
<td>Marker 4</td>
<td>0.086630</td>
<td>0.054615</td>
<td>-0.128801</td>
</tr>
<tr>
<td>Marker 5</td>
<td>0.084899</td>
<td>-0.059255</td>
<td>-0.078595</td>
</tr>
<tr>
<td>Marker 6</td>
<td>0.079271</td>
<td>-0.151334</td>
<td>-0.028775</td>
</tr>
<tr>
<td>Marker 7</td>
<td>0.189319</td>
<td>-0.253771</td>
<td>0.035572</td>
</tr>
<tr>
<td>Marker 8</td>
<td>-0.016507</td>
<td>-0.236065</td>
<td>0.047023</td>
</tr>
</tbody>
</table>

Fig. 16 (a) the process of the measurement when the subject bends 60°; (b) the spine shape of the subject in 60°

- **Bending 60°.**
  Fig. 16(a) shows the process of the measurement when the subject bends 60° and Fig. 16(b) the spine shape on the right. Table 4 presents the coordinates of markers obtained from the program when the subject bends in 60°.
Table 4 Results of the coordinates of the each marker

<table>
<thead>
<tr>
<th>Bending 60°</th>
<th>X</th>
<th>Y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marker 1</td>
<td>0.057660</td>
<td>0.048900</td>
<td>-0.699285</td>
</tr>
<tr>
<td>Marker 2</td>
<td>0.073715</td>
<td>0.036915</td>
<td>-0.575067</td>
</tr>
<tr>
<td>Marker 3</td>
<td>0.077111</td>
<td>0.016654</td>
<td>-0.458438</td>
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<tr>
<td>Marker 4</td>
<td>0.075184</td>
<td>-0.019821</td>
<td>-0.349433</td>
</tr>
<tr>
<td>Marker 5</td>
<td>0.077160</td>
<td>-0.076177</td>
<td>-0.225248</td>
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<tr>
<td>Marker 6</td>
<td>0.059731</td>
<td>-0.141778</td>
<td>-0.099299</td>
</tr>
<tr>
<td>Marker 7</td>
<td>0.173905</td>
<td>-0.241907</td>
<td>0.008305</td>
</tr>
<tr>
<td>Marker 8</td>
<td>-0.037550</td>
<td>-0.225101</td>
<td>0.016833</td>
</tr>
</tbody>
</table>

The rigid body of the subject’s spine represented by the collection of markers and the spinal shape can be observed clearly. The coordinates of each marker and the distance between two markers are collected. This experiment proves that in the current laboratory environment, the human spine deformity system is usable and reliable for trunk distortion assessment.

3.5 Result Analysis and a Novel Evaluation Index for Spinal Deformity Progression Evaluation

In this section, a novel evaluation index for adolescent idiopathic scoliosis measurement and diagnosis is introduced to complement the existing assessment index, such as Cobb’s angle (Cobb 1948), the differences of shoulder height (Pun 1987), etc. The new evaluation index is based on the phenomenon of the tilt and deviation of the vertebrae in a scoliotic spine, which forms the tilt angles between each pair of adjacent vertebrae. The index is called Inter-Vertebra Angular Separation (IVAS).

The human spine composes 33 vertebrae, from which the upper 24 vertebrae are connected when evaluating the severity of scoliosis in this research. These form the cervical (top), thoracic (middle) and lumbar (bottom) regions of the spinal column. Each vertebra is separated by the upper and lower inter-vertebral discs that allow slight movement of the vertebrae and act as a ligament to hold the vertebrae together. For a scoliotic spine, the spinal shape presents a typical ‘C-shape’ or ‘S-shape’ curve in the thoracic region due to the curvature of the spinal column. The vertebrae are observed to deviate most from a vertical plumb line near the cervical-to-thoracic and thoracic-to-lumbar transition regions. At these specified regions, the inter-vertebral discs are found to rotate on the coronal plane, hence forming an angular separation between the pair of adjacent vertebrae. Since these angular separations reflect a curvature in the spine, they can be summed up along the entire spinal column to provide an index that can be compared with the Cobb’s angle. The larger the total angles of separation, the more severe is the deformity.

The formulation of the proposed index of IVAS is follows

$$IVAS = \sum_{i=1}^{n} \text{(angle between the } i\text{th and } (i+1)\text{th planes which are perpendicular to the spinal curve)}$$
The IVAS does not consider the inter-vertebra disc. The steps of calculating the IVAS include:
1) Obtain the positions and coordinates of the vertebrae of the subject’s spine obtained using the OptiTrack cameras.
2) Interpolate the points of the vertebra to form the spinal curve to simulate the shape of the scoliotic spine.
3) Through each position of the vertebra point on the curve, draw the perpendicular planes to the 3D curve which is the normal direction along the curve.
4) Calculate the angles between the pair of adjacent perpendicular planes.
5) The index of IVAS is defined as the summation of the angles between the pair of the perpendicular lines.
6) Compare the IVAS index against Cobb’s angle to obtain the further analysis.

Fig. 17 shows an example of a scoliotic spine from the interpolation of positions of markers to form the spinal curve.

![Fig. 17 An example of curve fitting algorithm applied to the spinal curve and the calculation of the angle between the adjacent perpendicular planes](image)

<table>
<thead>
<tr>
<th>Bending Angles (°)</th>
<th>Spinal Shape Type</th>
<th>Severity</th>
<th>Cobb’s Angle (°)</th>
<th>IVAS Index (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>C</td>
<td>Mild</td>
<td>8.0</td>
<td>8.5</td>
</tr>
<tr>
<td>30</td>
<td>C</td>
<td>Mild</td>
<td>12.0</td>
<td>17.5</td>
</tr>
<tr>
<td>45</td>
<td>C</td>
<td>Mild</td>
<td>14.5</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 5 lists the measurements, in ascending order of the four bending angles, on the interpolated curves of the subject’s back image using the original IVAS index. The Cobb’s angles used were measured directly from the 2D interpolated curves by ignoring the z-coordinates of the data samples instead so as to provide a means of comparison of the feasibility with the IVAS index and the Stewart platform system.

From the table above, it can be found that when the degree of subject’s bending angles become larger (from 0° to 60°), the Cobb’s angle and IVAS index both become larger which means the spinal curve is more distinct. As the IVAS index and Cobb’s angle change in the same direction, a linear correlation exists between the IVAS index
and the Cobb’s angle.

The Cobb’s angle and the IVAS Index values in Table 5 are plotted in ascending order on the same axes, as shown in Fig. 18.

![Fig. 18 Plot of the IVAS Index against Cobb’s Angle with $R^2 = 0.9552$](image)

The high positive correlation between the Cobb’s angle and the IVAS index method is highlighted in Fig. 18 with the regression equation of $y = 2.7699x - 12.19$, where the line graph representing IVAS and Cobb’s angle change in the same direction. The computed correlation coefficient of 0.9552 is very close to the value of 1, thus implying a strong positive correlation between these two indices. This shows that the proposed index of IVAS has potentially high usefulness and feasibility.

In this case, from the measurement of the IVAS index and Cobb’s angle, this subject presents mild spinal deformity that the further diagnosis is not needed.

4. CONCLUSIONS AND FUTURE WORK

This paper presents the design, development, construction of a spinal deformity measurement system for 3D spatial investigation of human spine shapes. To achieve better results and higher precision, three cameras are utilized simultaneously to attain sufficient redundancy to guarantee high accuracy and consistency of the measurement.

Besides providing 3D measurements of the anthropometric markers for positioning the vertebrae and 3D topology of the human back, the technique provides a user friendly interface and a detachable mechanical frame. A case study involving the trunk shape of a subject demonstrated the capability of the developed system to assess the spinal distortion and frontal angular parameter.

The proposed system and methodology in this study has potential benefits for providing an alternative approach in the following aspects:

Firstly, for scoliosis pre-detection, the system has the advantage of being able to
provide a new method supporting the forward bending test. Since the movements of the Stewart Platform can be controlled precisely using computer programs, the measurement procedures are concise, repeatable and output data can be recorded easily for future retrieval.

Secondly, this system can reduce manpower requirement as the nurse or clinician do not have to go to schools for the forward bending test for the pupils. Instead, only one trained-technician is sufficient for operating the system and conducting the tests. For this non-contact method, the system can make the subject more comfortable during the measurement through careful and proper system design. In addition, this method could be used regularly to track the progress of spinal scoliosis.

Thirdly, a novel human spinal deformity assessment index for this system has been developed. The strong linear relationship between this IVAS index and the benchmark index for scoliosis measurement of Cobb angle shows the usability and feasibility of the proposed index.

The idea of identifying and calculating spinal deformity is not new. However, there are few reported works in the field of applying Stewart platform in facilitating the detection of scoliosis.

For future work, further experiments of bending a subject into a series of angles will be conducted and more data of subject’s back images for each bending angle will be captured using the OptiTrack camera system. Besides, the image processing algorithm will be modified for further spatial accuracy test and measurement repeatability test.

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