3D DIGITAL PHOTOGRAMMETRIC RECONSTRUCTIONS FOR SCOLIOSIS SCREENING

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ABSTRACT:

Scoliosis patients typically undergo numerous spinal radiographs during which they are exposed to relatively high doses of ionizing radiation. This has raised concern regarding the effects of this repeated exposure. Modern technologies for assessing spinal deformities are based on assessment of the surface topography of the back in various ways. Photogrammetry can contribute in direct measurement of the patient's back and 3D reconstruction of surface shape. This paper describes the instrumentation, technique and the results of a portable system for screening for scoliosis. It is based on digital photogrammetric techniques and gives an accuracy of 1mm in 3D reconstruction of the back. From this, spinal deformations indices are derived and clinically tested for correlation to the Cobb angle radiographic measurements, which are considered the "golden standard" in scoliosis assessment.

1. INTRODUCTION - RATIONALE

Scoliosis is a deformity of the spine in which there are one or more lateral curvatures deviating from the midline in the coronal plane.

Scoliosis is the most common type of spinal deformity, which occurs approximately 2% to 3% in children ages 10 to 16 years, girls being more at risk for severe progression by a ratio of 3.6 to 1 (Nault et al, 2002).

Scoliotic patients typically undergo repeated spinal x-rays, during which they are exposed to high doses of radiation. This radiation exposure has been estimated to lead to an increased risk of cancer of up to 2.4/1000 scoliosis patients (Levy et al, 1996). Particularly since less than 10% of diagnosed scoliotic curves progress to require treatment (Reamy et al, 2001), it is highly desirable that all efforts be made to use non-invasive assessment of curve progression (Dickman et al, 2001a) (Patias, 2002).

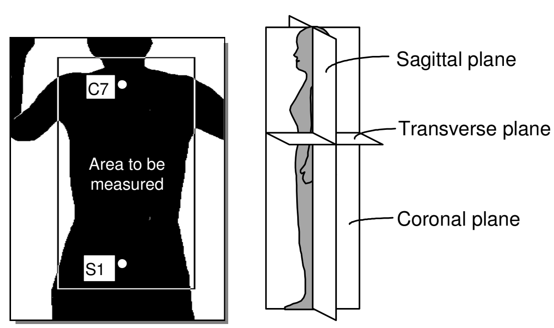
To this end, non-invasive systems have evolved, such as the handheld ''scoliometer'' (Bunnel, 1984, Burwell et al., 1990), Moire-fringe mapping (Takasaki, 1970, Moreland et al, 1981, Willner et al, 1982, Idesawa, 1982, Karachalios et al, 1999), the raster-based systems like the ISIS system (Weisz et al, 1988, Theologis et al, 1997), or the Quantec system (Goldberg et al, 2001, Thometz et al, 2000) or the Ortelius (Dickman et al, 2001b) scanners, and devices that scan 360^o torso profiles (Gomes et al, 1995, Sciandra et al 1995, Poncet et al, 2000, Schmitz et al., 2002), ultrasound systems (Suzuki, et al, 1989) and last but not least stereo-photogrammetric systems (Frobin, et al, 1981 and 1983, Thomson, 1985, Hill et al, 1992, Sechidis et al, 2000).

Based on recent technological advances and on a better understanding of medical needs, the system we present here is a digital 3-camera system, automated to a high degree, and produces medically meaningful indices for scoliosis screening.

2. GENERAL ASPECTS OF SCOLIOSIS

2.1 The anatomy of the spine

The human spine is a flexible column formed by a series of 33 vertebrae. Normally scoliotic deformations occur between vertebrae L1 and C7 (Fig.1a). These deformations occur in 3D space and thus it is common in medical practice to use 3 planes (mutually perpendicular) to describe it: the *transverse* (or lateral) plane, the *sagittal* plane, and the *coronal* plane (URL1, URL2, Pearson, 1996) (Fig.1b).



(a) **(b)**

Figure 1. Basic anatomy of the spine *(after Pearson, 1996).*

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

2.2 Scoliosis as 3D deformation of the trunk

Although scoliosis is characterized by lateral deviation of the spine, a 3D deformation actually is responsible for geometric and morphologic changes in the trunk and rib cage (Nault et al. 2002).

Patients with abnormal findings on initial physical examination are often then referred for a more thorough examination, usually using radiographs. From these, the Cobb angle (ie. the degree of curvature) (URL4, Cobb, 1948), which is considered the “golden standard” in scoliosis evaluation, is measured (Fig. 2). Unfortunately, even Cobb angle has a reported 95% confidence interval for intra-observer and inter-observer variability of 3–5° and 6–7°, respectively (eg. Pruijs et al, 1994).

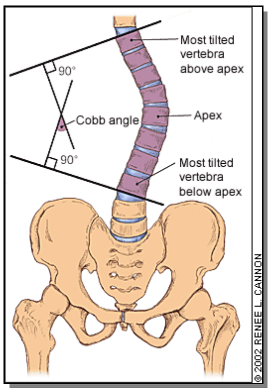
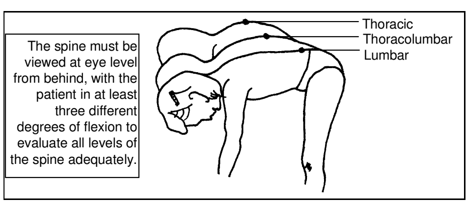


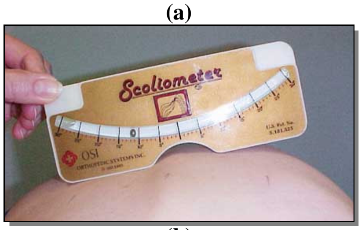
Figure 2. The definition of the Cobb angle.

2.3 Scoliosis evaluation from back shape

The principal screening test for scoliosis is the physical examination of the back, which includes the Adams forward-bending test (Fig. 3a), while the “scoliometer” (Fig. 3b) quantities the trunk deformation.



(a)



(b)

Figure 3. (**a**) The Adams forward-bending test and (**b**) the “scoliometer”

3. THE DESIGN OF THE PHOTOGRAMMETRIC SYSTEM

3.1 The choice of cameras - Interior orientation

Format	**SLR**
Max resolution	**3456x2304**
Image ratio w:h	**3:2**
Effective pixels	**8.0 million**
Sensor size	**22.2x14.8mm**
Maximum shutter	**1/4000 sec**

Figure 4. The Canon EOS 350D / Digital Rebel XT

In Fig. 4 the technical characteristics of the camera used is shown. The choice of this camera assures stable interior geometry, (to be calibrated), small pixel size, high radiometric resolution, ability of manual focus, ability of simultaneous use of more than one camera, high shutter speed and low cost.

For the camera calibration a portable calibration filed is used, while the system provides for auto-calibration procedure as well.

3.2 The system setup

The whole system (Fig. 5) comprises by a set of 3 similar cameras, a notebook, a portable calibration field and the necessary software. Set up parameters are shown in next table :

nominal focal length (f)	**28 mm**
distance from object (D)	**4 m**
average image scale (s)	**1:150**
pixel size (p)	**7.5 μm**
groundel size (P)	**1.1 mm**

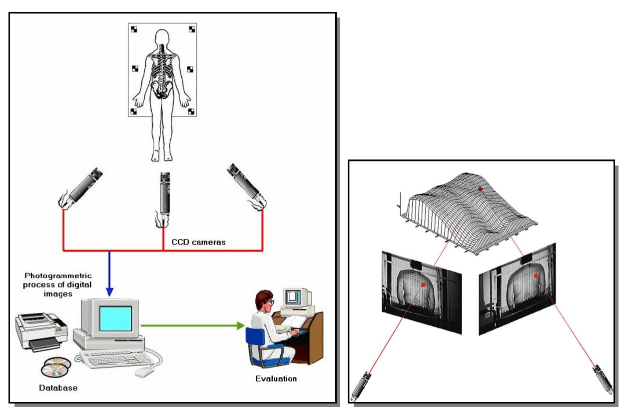


Figure 5. The proposed system

The use of multi-images assures high quality of measurements and redundancy in automatic procedures. The software comprises from the following modules :

- Calibration – Interior Orientation
- Data acquisition
- Image matching
- Triangulation – Autocorrelation

- Back surface generation – Quality evaluation
- Generation of scoliosis indices - Reports
- Manual medical measurements – CAD operability
- Connection to a Medical Information System (MIS)

3.3 The DSM of the back

With automatic image matching the 3D coordinates of a vast amount of surface points are computed. In fact the system is designed to evaluate points on a grid with a size of 1cm on the back. Due also to the fact that the surface is smooth without any abrupt changes, the modeling of the back is excellent.

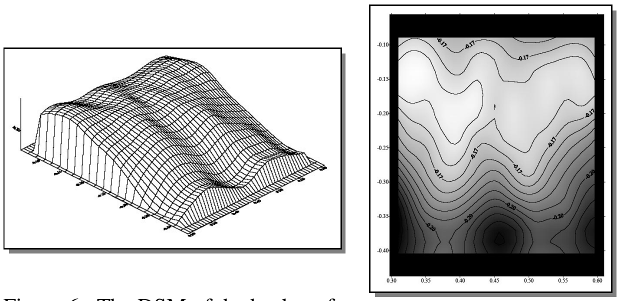


Figure 6. The DSM of the back surface

3.4 Quality control issues – Expected accuracies

a. Triangulation

Assuming that image coordinates are measured with a nominal accuracy of 1/3 of a pixel (p), ie.: $\sigma_o = 0{,}3p$, and the average distance of the control points is i = 2b (b = camera base), then the accuracy of image coordinates is (c = the camera constant) :

$$\sigma_{xy} = 2\sigma_o = 0.6p$$

$$\sigma_z = 2\frac{c}{b}\sigma_o = 3.34\sigma_o = 1.67\sigma_{xy} = 2\frac{1}{0.60}0.3p = 1p$$

i.e. in our system set up we should expect :

pixel size = 7,5µm ➔ $\boldsymbol{\sigma_{xy}}$ **= 4,5 µm,** $\boldsymbol{\sigma_Z}$ **= 7,5 µm**
image scale = 1 : 150 ➔ $\boldsymbol{\sigma_{xy}}$ **= 0, 7 mm,** $\boldsymbol{\sigma_Z}$ **= 1,1 mm**

Actually, this is the worst case, since the overlap is going to be almost 100% and a 3rd camera is going to be implemented.

b. DSM production

The expected accuracy of the DSM is :

σ_Z = 0.1 – 0.33 ‰ c

ie. in our system set up we should expect :

c = 28 mm ➔ $\boldsymbol{\sigma_Z}$ **= 2,8 – 9,2 µm**
image scale = 1 : 150 ➔ $\boldsymbol{\sigma_Z}$ **= 0,4 – 1,4 mm**

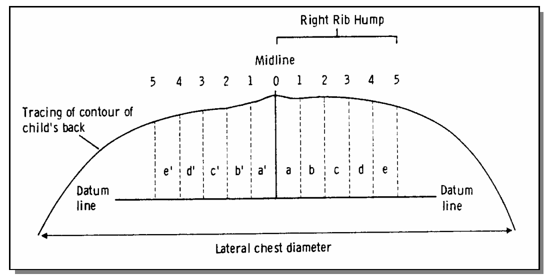
From the above analysis we conclude that the expected accuracies of the proposed system cover the needs of the application in hand.

4. THE CLINICAL IMPORTANCE OF PHOTOGRAMMETRIC DATA

4.1 Scoliosis evaluation indices used by the medical society

In the medical literature, one can find several scoliosis evaluation indices, which are based on back surface data (eg. URL3). Most widely used seem to be :

- **CTAS** (Pearson, 1996) (Fig. 7), which is similar to ATI (Angle of Trunk Inclination) (Pearson, 1996) or ATR (Angle of Trunk Rotation) of (Pruijs et al, 1995a,b). This index measures the back asymmetry and simulates the scoliometer.



Crude Trunk Asymmetry Score (**CTAS**):

$$\mathrm{CTAS} = (a - a') + (b - b') + (c - c') + (d - d') + (e - e')$$

Figure 7. The CTAS index *(after Pearson, 1996)*

- **PA** – Posterior Anterior (Tattersall et al, 2003) (Fig. 8) is an index that measures the back asymmetry with respect to the C7-L5 axis, which in some researchers is materialized by a plumb line (Hay et al, 1996)

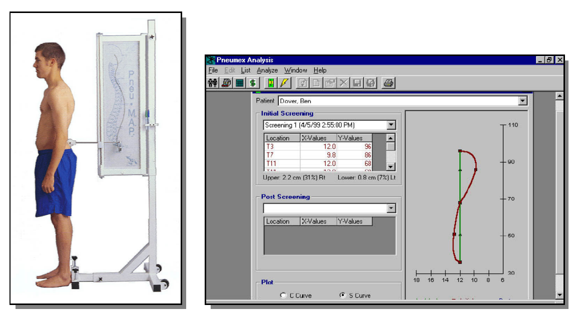


Figure 9. The PA index *(after Tattersall et al, 2003, Hay et al, 1996)*

- Indices of the **ISIS** (Theologis et al, 1997) and the **Quantec** (Theomez et al, 2000) Systems
    - *Q angle*
    - *LA – Lateral Asymmetry*
    - *TA – Transverse Asymmetry*
    - *VA – Volumetric Asymmetry*
    - *HS – Hump Severity*
    - *IM – Imbalance*
- **Jaremko indices** (Jaremko et al, 2001, 2002a,b) (Fig. 10) which include 6 main indices from a total of 48, with the general description **BSR** – Back Surface Rotation. These indices are checked for their correlation to Cobb angle.

On a similar concept Nault (Nault et al, 2002) proposes 6 indices, which show high correlation to Cobb angle, as well. These indices are similar to Jaremko's.

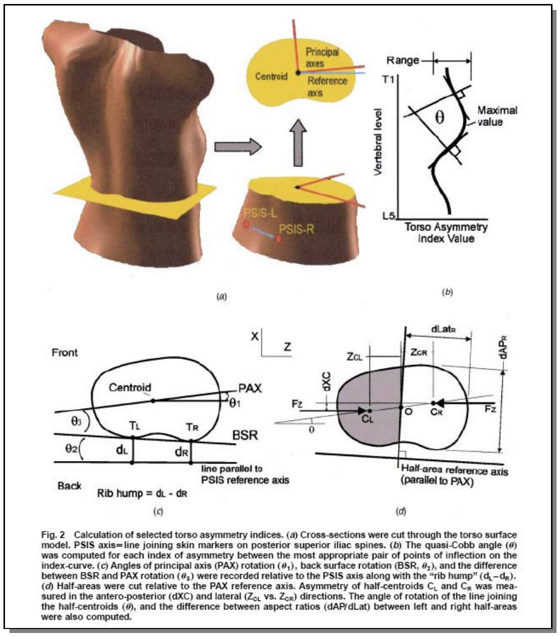


Figure 10. BSR indices of Jaremko *(after Jaremko et al, 2001)*

4.2 The proposed evaluation indices

In order for the photogrammteric 3D data of the back surface to have clinical relevance and to be practically useful to medical society, a number of indices are produced, as shown next.

The effort is that these indices are meaningful to doctors, according to their clinical practice and easy to derive from the original data.

- **Index Y_1 :** This index show the rotation around the Y axis of back symmetry and corresponds to the PAX-BSR of Jaremko (Jaremko et al, 2001, 2002a,b).

- **Indices Z_1 and Z_2 :** These indices show the rotation around the Z axis (perpendicular to the back surface) and correspond to the indices of (Nault et al, 2002, to indices TA and HS of the ISIS system, and partially to the Q angle of the Quantec system.

- **Index ASY_1 :** This index show the asymmetry with respect to coronal plane and corresponds to index PA of (Tattersall et al 2003) and (Hay et al, 1996), στο δείκτη LA of the ISIS system and to various indices of Jaremko.

- **Index ASY_2 :** This index show the asymmetry with respect to traverse plane and corresponds to index CTAS of (Pearson, 1996).

- **Index ASY_3 :** This index show the combined asymmetry with respect to traverse and coronal plane and corresponds to index VA of the ISIS system and to various indices of Jaremko.

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<http://www.geoimaging.com.cy/scoliosis/index.htm>

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[URL3] Scoliosis Research Centre - Back Shape Modelling http://www.ece.ualberta.ca/~scoweb/projects/modelling.html

[URL4] Cobb angle. http://www.e-radiography.net/radpath/c/cobbs-angle.htm