MEASUREMENT AND ANALYSIS OF HUMAN BACK SURFACE SHAPE

Alan R. Turner-Smith
J. Derek Harris
Oxford Orthopaedic Engineering Centre
University of Oxford
Nuffield Orthopaedic Centre, Oxford, United Kingdom

ABSTRACT

The shape of the back is an important factor in the clinical assessment of various spinal disorders. Moire topography and other photographic processes have been widely used for such measurements, but without numerical analysis these methods at best give only a qualitative record of back shape. Digitising photographs for a more consistant analysis often takes so long that results are not available in the clinic.

An optical scanner is described comprising a 35 mm projector and a computer-linked television camera mounted together in a box which swings vertically. The projector shines a horizontal plane of light which is viewed at an angle from below by the television camera. The known geometry of the system allows computation of the three-dimensional co-ordinates of the line formed by the plane of light as it falls on a surface. The line is scanned over the back in less than two seconds to build up a record of the entire surface shape. At the same time positions of landmarks identified by black markers are recorded. The method of calibrating the instrument is described and the accuracy is shown to be $\pm$ 2.5 mm over a volume 450 mm x 1400 mm x 500 mm.

Shape data are analysed to extract numerical parameters of interest to the clinician and to display the back shape in a consistant manner. Some methods of analysis are discussed.

INTRODUCTION

Figure 1 illustrates the unpleasant deformity of scoliosis which is severe enough to warrant assessment and possible treatment of about 0.3 per cent of the population (Keim, 1979; Desmet et al, 1981). The aetiology of about 70 per cent of cases, referred to as 'idiopathic', is unknown. In these cases, progression of the disease is usually most rapid during the adolescent growth spurt, during which period it is not unusual to take several radiographs each year. The majority of patients followed in scoliosis clinics, however, never reach the point where surgical intervention is necessary. Even when surgery is performed, it is often aimed at improving cosmetic appearance as much as improving the mechanical stability of the spine and function of the pulmonary system. Indeed, there is an opinion that minimal surgical intervention is best for all but severe cases, and that treatment is desirable chiefly for cosmetic appearance (Weinstein et al, 1981). Not only does the back shape give an indication of the severity of the disease, but also a change of shape will reflect the effectiveness of treatment (exercise, bracing, etc) and underlying skeletal changes.

Although the clinician's eye is a sensitive gauge of shape, he cannot retain his impression from one clinic to the next, nor does he have available any other conventional method of recording back surface shape. Various methods have been proposed to record back surface shape ranging from a simple conforming ruler (Burwell, 1983) to full conventional photogrammetry (Herron, 1972). Non-tactile methods have the advantage of minimal interference with the subject and of these moiré topography has been most widely exploited (Takasaki, 1970; Willner, 1979;

Adair et al, 1981. See also the Proceeding of the internantional symposia on Moiré Topography and Spinal Deformity, 1981 and 1983). It can produce pictures quickly and, as illustrated in Figure 2, the appearance of a contour map of the back is subjectively convincing.

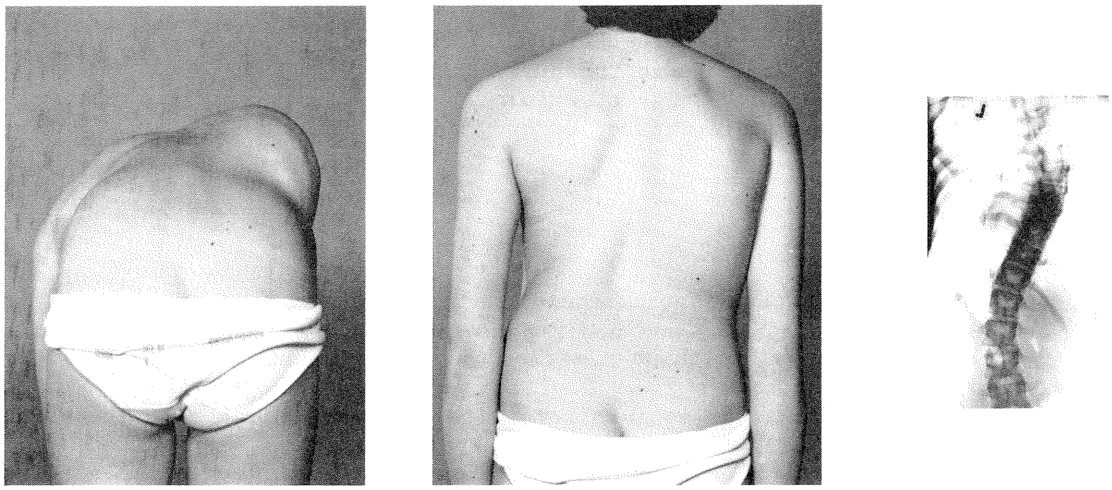

Fig. 1 Clinical appearance and radiograph of a girl suffering from a severe right thoracic scoliosis

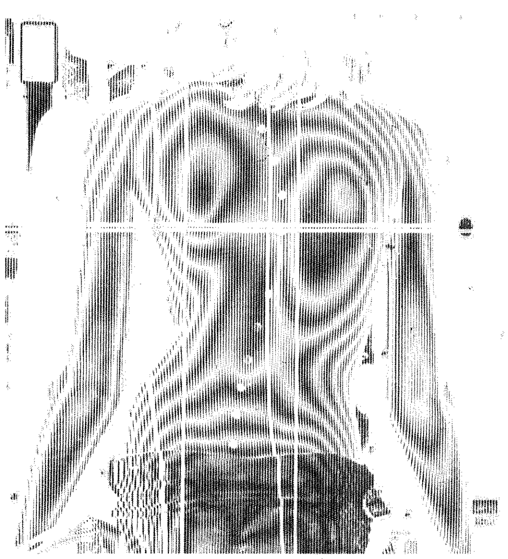

Fig. 2. A typical moiré topograph of a severe right thoracic scoliosis

Two particular problems are associated with the use of moiré topography. First, the fringe contours of the moiré topograph show not only the shape of the back, but the posture of the patient. If this position changes even slightly, the appearance of the picture is markedly changed. For comparative study therefore the patient must be rigidly constrained. In doing this there is the possibility that, in addition to the normal variations of stance which occur from time to time, a significant postural alteration caused by the deformity will be eliminated. Second, the contour picture itself does not provide numbers which can be compared. Various methods have been proposed to assist in the analysis of moire topographs and to quantify the deformities due to scoliosis (Willner, 1979; Suzuki et al, 1981; Ishida et al, 1982; Moreland et al, 1981; Drerup, 1972, 1981; Shinoto et al, 1981), but the measurement and analysis procedures add time and complication to the moire technique, nullifying its main attractions of speed and simplicity.

This paper describes a direct television-computer system and software, codenamed 'Isis', by which a patient's back may be measured, analysed and plotted by a computer within a period of 7 minutes. The system has been used successfully to assess all scoliosis patients attending regular weekly clinics at the Nuffied Orthopaedic Centre since October 1983 (Turner-Smith and Harris, 1985).

THE ISIS SCANNER

The scanner uses a structured light method similar to the photographic technique of Joel (1974) in which the pattern of light is a simple plane. The principle of the system is shown in Figure 3. A standard 625-line television camera and a 35 mm projector are mounted in a fixed relationship within a unit which can swing about a horizontal axis. The projector produces a horizontal plane of light, which the camera views at an angle from below. The two-dimensional co-ordinates of the line, seen as the light falls on a three-dimensional surface, are recorded directly by a PDP 11/23 mini-computer (Digital Equipment Corporation) using a high speed television interface ('Vicon', Oxford Metrics Ltd). These co-ordinates, together with a full knowledge of the geometry of the system, enable the three-dimensional shape of the illuminated strip of surface to be computed. By swinging the camera/projector unit about its axis, a complete record of the three-dimensional shape of an entire surface can be built up. The advantage of having a simple pattern of light is that three-dimensional co-ordinates can be computed very quickly and unambigously. The disadvantage is that the pattern has to be scanned across the object. However, for the measurement of human back shape, a scan time of 1 - 2 seconds yielding 50 - 100 television frames is perfectly acceptable.

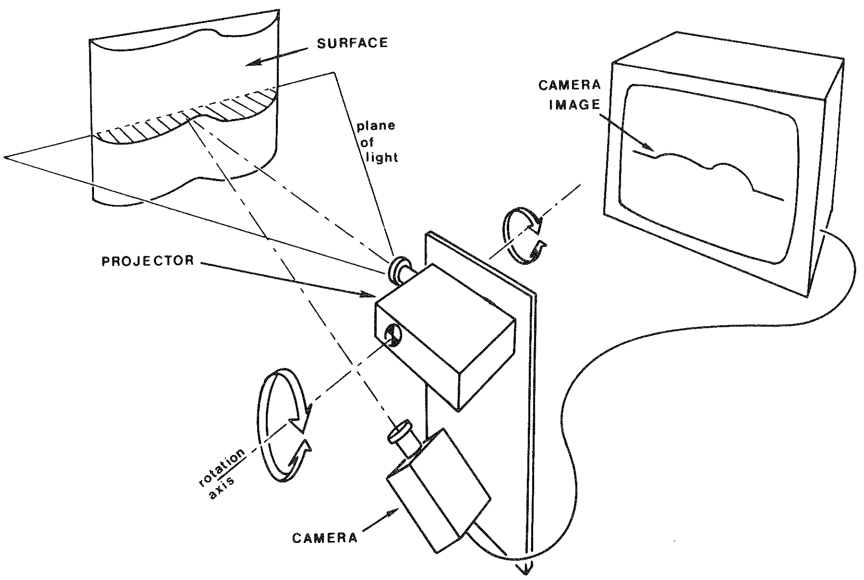

Fig. 3

Principle of operation of the Isis scanner

The mechanical layout of the scanner is shown in Figure 4. The 35 mm projector contains a slide of a single horizontal white line. The light beam from the projector is reflected off a mirror near the axis of rotation. The optics aligned so that the light appears to come from the axis of rotation, although the calibration does not demand precise alignment. The television camera is mounted on its side so that the television scan lines are vertical. This axis has the higher resolution, and is the one involved in measuring the depth component of the object. The box is driven by a rod attached to a belt, driven in turn by a speed-controlled motor.

The angle of the box is measured by a linear potentiometer, the signal from which is inserted at the top of the television picture as a short bright bar. The only connection necessary between the scanner and the computer is thus a video signal into the Vicon television interface.

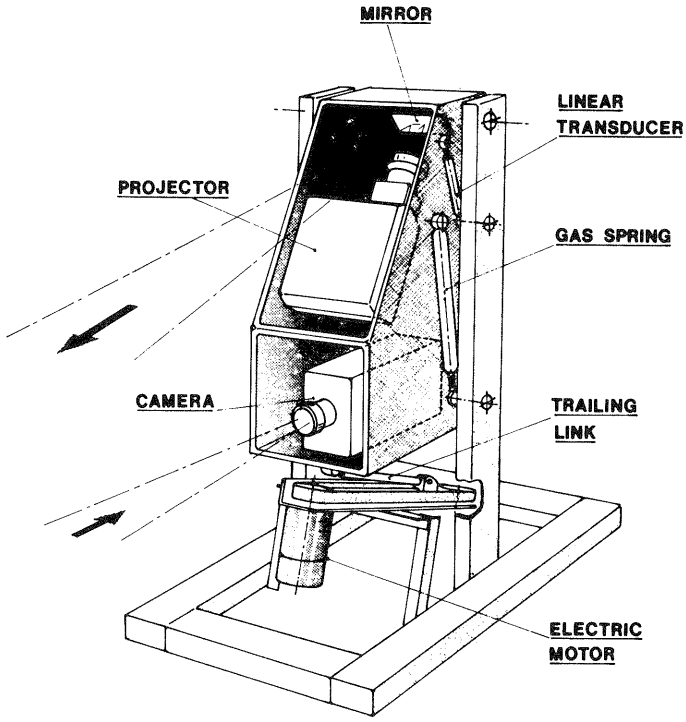

Fig. 4 Mechanical layout of the Isis scanner

GEOMETRY OF THE SYSTEM

Computation of the surface shape from television coordinates was achieved by consideration of the geometry of the system in the two planes as shown in Figures 5 and 6, initially assuming perfect alignment of television, projector and axis of rotation.

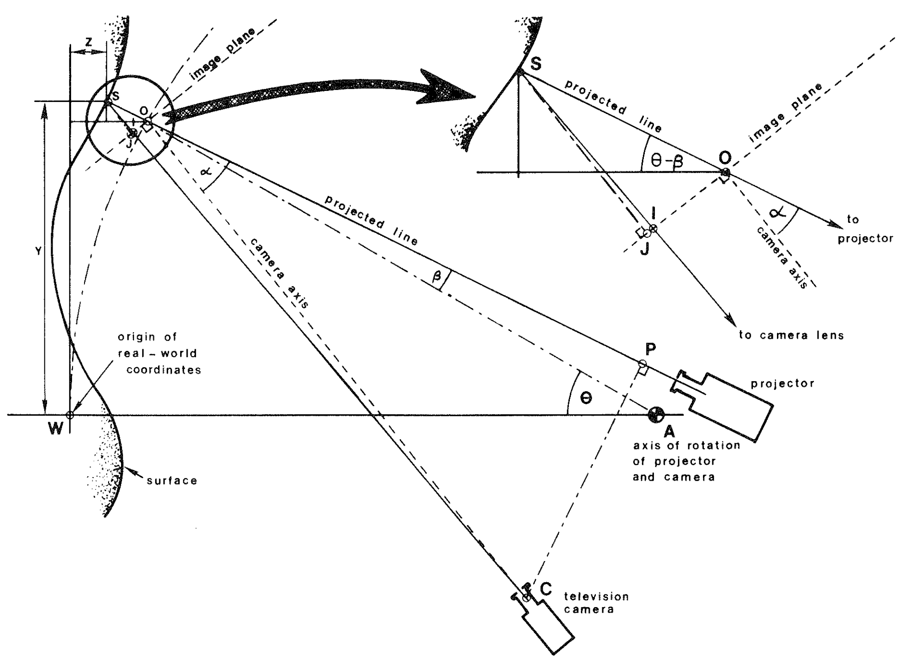

Fig. 5 Geometry of elevation

From Figure 5 the distance OS (from the origin of image plane to the intersection of projected line and the surface) was expressed in terms of CP (perpendicular distance of the centre of perspective of the television camera lens to the projected line), OI (apparent vertical position of S in the image plane) and α (angle between the projected line and the optical axis of the camera). This expression was used to establish formulae for the real world coordinates, X and Y in terms of fixed constants of the system: AW, CP, α, and β (angle of the projected line to the radius OS), and the variables OI (measured by the television camera) and θ , the angle of the scanner unit.

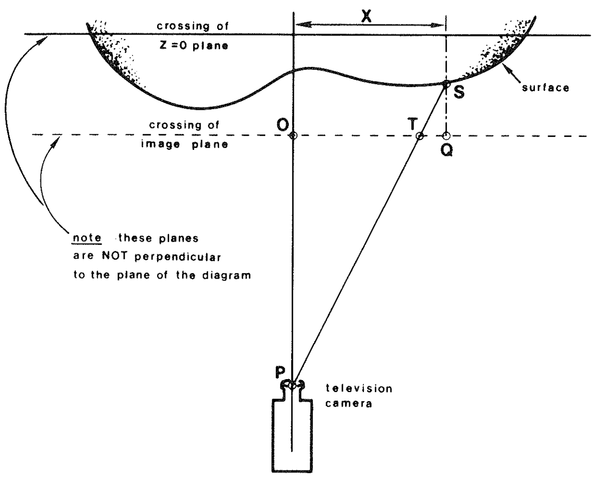

Fig. 6 Geometry in plane of projected line

From Figure 6 the real-world coordinate X is expressed in terms of OS, CP, OT (the apparent horizontal position of S in the image plane of the camera) and α.

A full description of the geometrical calculations and details of calibration have been submitted for publication.

CALIBRATION

Calibration was conducted by scanning a board with 64 markers at known positions within an over-all volume of 350 x 750 x 100mm, see Figure 7. Rough values for some fixed constants were provided, but the calibration scheme refined these and computed all other geometrical parameters. Non-linearity of the television camera raster was allowed for in both axes up to third order. The appearence of the scan of the object followed a general pattern, i.e. the spots appeared in an expected order and their apparent position indicated the perspective of the camera. Analysis of these patterns enabled each of the geometrical parameters to be computed in turn, albeit some with greater accuracy than others. When all the parameters were found the theoretical positions of the 64 markers were re-computed from their television coordinates. The parameters were refined in the order of their likely errors to minimise the difference between the true and computed coordinates.

PERFORMANCE

The method of calibration was verified by scanning the calibration object and a surface of known dimensions at different angles and distances from the initial calibration position. The RMS error of relative measurements within a volume of 350 x 750 x 100mm (which is large enough to encompass human back shapes) was ±1.1mm in X, ±1.5mm in Y and ±1.7mm in Z. These errors changed by ± 0.2mm from day to day and were close to the theoretical limits of accuracy of the system imposed by quantisation error of the television scan and digitisation, which also determined the resolution of the system, about ±0.5mm. The limits of the possible scan volume imposed by the camera frame and scan angle were 450 x 1400 x 500mm. At the edges of this larger volume the errors increased to ±1.2mm in X, ±3.0mm in Y and ±3.5mm in Z.

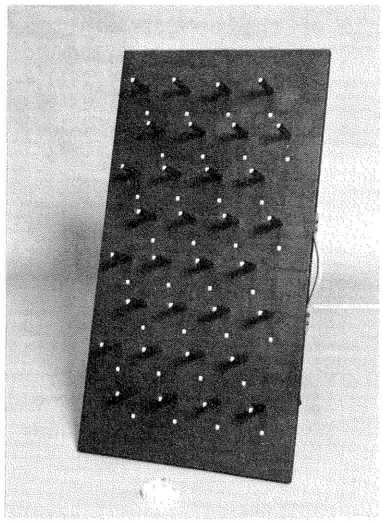

Fig. 7 Calibration object

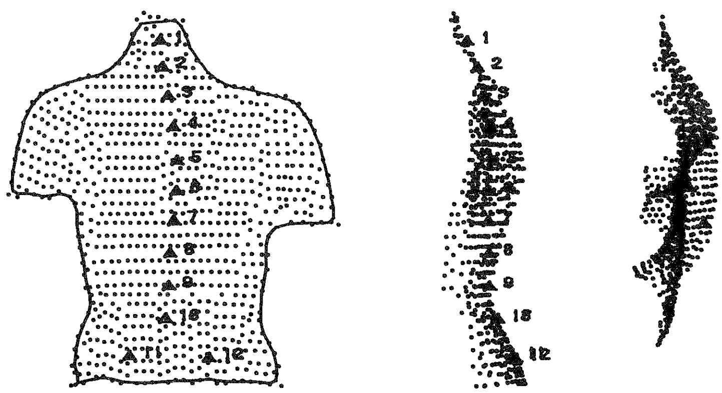

Fig. 8 Three-dimensional data scanned from a scoliotic back as seen viewed along the Z, X and Y axes

The software for calibration and surface shape scanning was written in Fortran 77 for use on a DEC PDP 11/23 minicomputer running the RSX operating system. Calibration took about 3 minutes to run while conversion of a file of television coordinates of a human back, produced in real time by the Vicon television interface, took about 5 minutes. The surface was descibed by 1000 - 2000 co-ordinates scattered evenly over the back (see Figure 8).

The scanning system was also designed to recognise black rectangles 9mm wide x 16mm high. These were used to identify anatomical features on the back. The positions of such markers were shown to be identifiable to within ±2mm in X, ±4mm in Y and ± 3mm in Z.

METHOD OF PRESENTATION

The Isis scanner can measure surface shape but the clinician who uses the information is interested in the presentation and how quickly it is available, rather that details of data collection. The form of presentation is shown in Figure 9. It was developed over a period of 6 years of collaboration with clinicians at the Nuffield Orthopaedic Centre and can be applied to both digitised moiré topographs and Isis scans. The measures are substantially independent of minor changes in the patient's posture from one clinic to the next, yet sensitive to significant improvement or deterioration of the disease.

On the left are shown horizontal cross-sections at ten levels up the back from sacrum to vertebra prominens, marked with the average angles of rotation of the surface over the central portion of the cross-section. In the centre is shown the outline of surface data and the location of the marks which indicated palpated anatomical features of the spine: the vertebra prominens, the dimples of Venus and the line of the spinous processes between. The rotation of vertebrae at each level may be roughly gauged from rotation of the skin over them. The extra lateral displacement of the centre of the vertebral bodies from the line of the palpated spinous processes is indicated by the broken line which shows an estimated line of the spine. The straight angled lines are drawn at the points of inflexion of this line to model the conventional radiographic "Cobb angle" measure. The surface-derived angles correlate well with radiographic measures (r=0.82) for most unoperated scolioses (Turner-Smith and Harris, 1985). On the right are three lateral profiles taken following the curved palpated line of the spine with measure of maximum kyphosis and lordosis.

The clinician can follow whichever feature of the presentation best represents the deformity he wishes to treat. For example kyphotic deformity can be monitored as well as scoliosis.

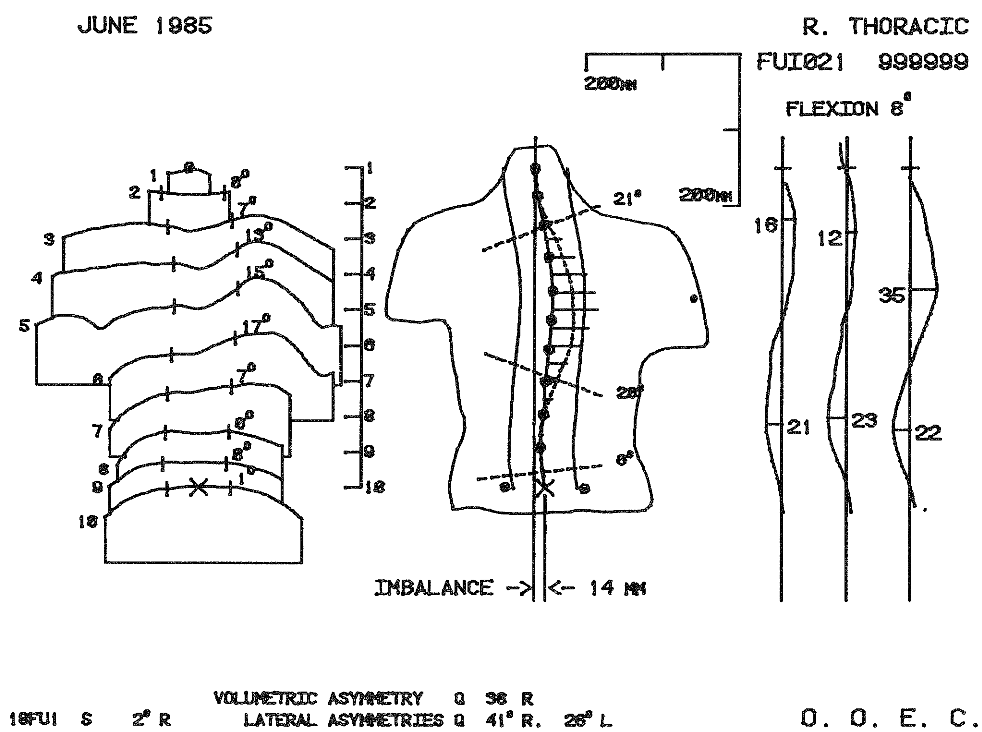

Fig. 9 Presentation of back shape for the scoliosis clinic

CONCLUSION

A permanent record of the shape of the human back is a valuable asset in the assessment of some spinal disorders. The instrument described here, codenamed Isis, provides an accurate presentation of back shape within a few minutes of scanning the subject. It has been in weekly use in a scoliosis clinic since 1983.

Within an overall measurement volume of 450 x 1400 x 500mm Isis can measure surface shape to an accuracy of about ± 2.5mm relative to other points within a local volume of 350 x 750 x 100mm. The position of black marker squares stuck to the skin surface are also identified and measured to a similar accuracy.

Isis has been successfully developed as a commercial product by Oxford Metrics Ltd. Their instrument has a similar performance in measurement and is particularly simple for paramedical staff to use. Their machine has been installed in a number of scoliosis centres throughout the UK, USA and Canada, eight of whom are cooperating in a trial to assess the method of back shape analysis as a tool for the assessment of ideopathic adolescent thoracic scoliosis.

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