Development of an Apparatus to Evaluate Adolescent Idiopathic Scoliosis by Dynamic Surface Topography

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Abstract. For cases of Adolescent Idiopathic Scoliosis (AIS), commonly the first indicator is a change in the surface shape of the back over time. A proportion of patients so diagnosed require surgical intervention to prevent further progression and to improve cosmesis. The results of a preliminary literature survey have revealed that significant work has already been published on the static acquisition and analysis of back surface shape. There is new interest in establishing correlations between breathing, posture, the underlying spinal deformity and changes in the surface topography of the back during clinical sessions together with an increased focus on the impact of the cosmetic defect on the patient and in the measurement of pre and post-operative dynamic capability.

The continuing development of an apparatus based on established optical motion capture technologies, that generates a sequence of tri-dimensional images and provides measurements derived from changes in the position of anatomical reference landmarks and of the surface topography of the back will be presented. If, using the same landmarks, the trunk range of motion could be captured concurrently, it is hoped that the resulting data would form the basis of a useful clinical study.

1. Introduction

Between 1984 and 1988, the author was involved with the development and introduction of the commercial version of the Integrated Shape Imaging System (I.S.I.S.) [1] based on the previous work of Turner-Smith and Houghton [2, 3]. For the past twenty years he has concentrated on the development and application of optical motion capture technologies to the fields of clinical gait analysis, rehabilitation, sports biomechanics and ergonomics. Within the last decade, the same technology has been widely applied to the creation of animated background characters used in the crowd scenes of many major film productions including Titanic, Troy, Gladiator, Star Wars II and III. In recent years the technology has advanced to a degree where it is now being used to capture the subtleties of characteristic whole body motion and facial expressions of well known actors as the main characters in feature films such as *The Polar Express* and *Beowulf*. The aim of the study was to investigate how it might be possible to apply similar technologies and experience to synchronously capture video images to quantify, in three dimensions, the changes in the position of surface anatomical landmarks and back surface shape during clinical presentations.

Earlier work by many researchers concentrated on attempting to reduce the radiographic exposure to AIS patients by investigating if there was a reliable correlation between the progression of an underlying spinal deformity and changes in back surface topology over time [4,5,6]. The techniques applied and the relational algorithms developed were found to be prone to error by postural and non-spinal artifacts and were in-sufficiently robust to accommodate all cases so limiting their measurement sensitivity, specificity and usefulness as general clinical tools.

A recent paper [7] focussed on the need to quantify the cosmetic defect of spinal deformity and work has been published on the evaluation of tri-planar spine range of motion following spinal fusion [8], implying a need still exists for apparatus [9] that can dynamically acquire the location of pre-defined anatomical surface landmarks and back topology to within clinically acceptable accuracies.

2. Materials and Methods

Previous work using optical motion capture technology has been published. Rotelli and Santambrogio [10] placed an array of passive detectable markers across the surface of the back and captured the resulting tri-dimensional positions. Aliverti et al. [11] used a laser scanning mechanism to apply a moving point of light to the surface synchronized to each acquisition of the apparatus optical sensors. Rotelli and Santambrogio's method had the advantage of presenting an absolute measure of the location of all markers during each acquisition but would not be a feasible option for routine clinical sessions due to the time needed to apply sufficient markers before each measurement. The approach by Aliverti et al. would have been prone to errors introduced by postural and breathing artifacts, so was not considered further.

2.1 Data Acquisition The study used an obsolete and modified 6 Camera, VICON motion capture system (Vicon Motion Systems Ltd., Oxford, U.K.) to acquire anatomical landmark positions and surface data simultaneously at a rate of 60 frames/second. Fig. 1 depicts the arrangement of two groups of three, optically isolated, cameras and a projector used to generate an array of points.

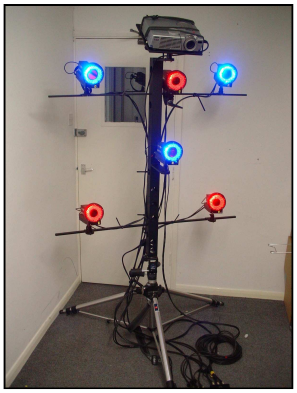

Fig. 1. Acquisition Apparatus

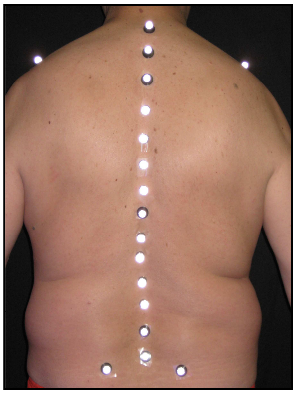

Fig. 2. Anatomical Markers

Fig. 3. Projected Point Cloud

VICON systems use spherical markers coated (Fig. 2) with a material that reflects light directly back to a strobed source surrounding a camera lens. The cameras are shuttered to open only during a strobe flash and contain filters optically matched to the spectra of the light source. Only circular bright markers will be sampled by each camera sensor, independent of the rate of subject movement and ignoring skin, fabric and other objects within the field of view. The centre of markers are calculated as positions within the two dimensional image illuminating the sensor during a given frame by analyzing the relative intensities of light impinging onto groups of adjacent pixels. Before each capture session, calibration objects with markers attached at known positions are used to establish the global coordinate system of the measurement volume; the physical position and orientation of each camera and the scaled relationship between the acquired coordinates and the actual positions. The optical distortion of the cameras (particularly from the lenses at the corners) is also calculated and a linearization correction applied to each subsequent frame captured. Within the measurement volume defined by the lenses chosen and the distance to the object, accuracy of marker centre reconstruction was determined by experiment to be within a mean of ± 0.1mm, S.D. 0.3mm, n = 4,500.

To detect the markers, three shuttered, strobing cameras were configured to emit and detect light in the visible red spectral region (660 nm). Three further passive cameras were fitted with optical, short-pass filters to exclude light in the red spectra but to allow passage of the image of the projected surface point cloud (Fig. 3) to the camera sensors. The centres of the points were determined in the same way as for the markers.

Providing a minimum of two calibrated cameras see a marker or a point anywhere within the measurement volume, the third dimension can be calculated in exactly the same way as humans estimate distance with two offset eyes viewing a common object [12]. The presence of a third or more cameras further improves the reliability of point and marker re-construction.

2.2 Surface Data Processing Figures 4 and 5 depict the presentation of anatomical marker (Fig. 4) and surface point cloud (Fig. 5) locations in two dimensions, acquired from a single frame from cameras in each group. Supporting software has been developed to automatically separate marker and point data into two files for further processing into frames of three–dimensional coordinates.

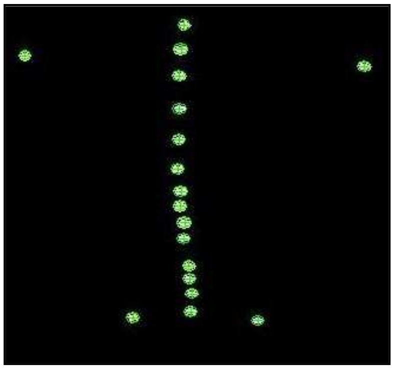

Fig. 4. Anatomical Markers

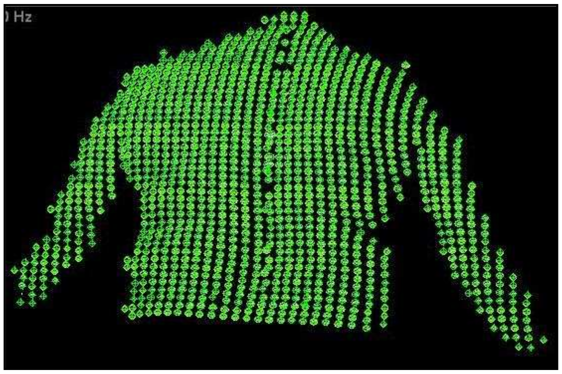

Fig. 5. Surface Cloud Points

The resulting three dimensional data were normalised to a reference plane defined by the positions in each frame of the markers placed by palpation over the vertebra prominens (C7/T1) and the left and right posterior superior iliac spines (PSIS) [1]. Two additional markers were applied to the acromion to provide a measure of shoulder droop. For pre-operative cases, 10-13 additional markers were applied to the spinous processes and a tri-planar cubic spline interpolation calculated to define the delineation between the left and right sagittal surface sections. Placement of markers in post-operative cases should follow the convention established by Jefferson et al. [13]. Boundary cubic splines were also calculated based on a proportion of the height of the spine between C7/T1 and the bisection point between the PSIS to remove data not required for further analysis such as the arms. Algorithms have been developed that automatically identify the reference markers and order spinous process markers in most expected cases within defined degrees of freedom. Table 1 lists the clinical data that are calculated and Fig. 6 depicts an example graph of changes in imbalance over 440 frames (7.3 s) captured from a normal subject.

Table 1. Calculated Parameters

Parameter	Units
Height	mm
Tilt	degrees (+/-)
Imbalance	mm (L/R)
Pelvic Tilt	degrees (L/R)
Pelvic Obliquity	degrees (to L/R)
Shoulder Droop	mm (L/R)

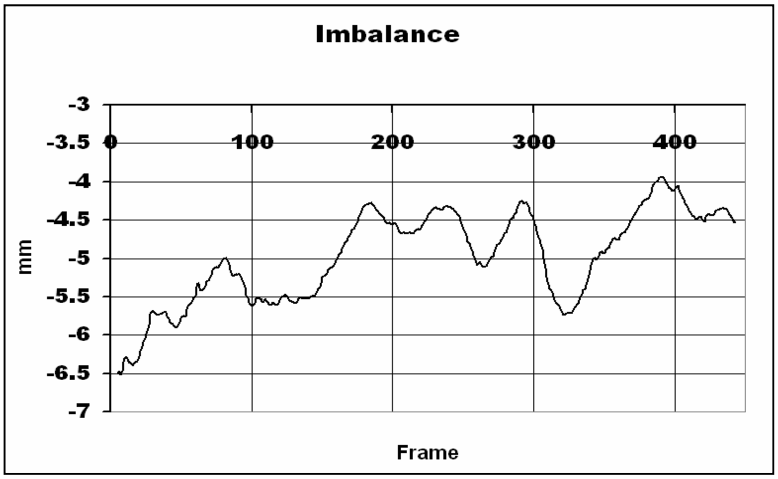

Fig. 6. Variations in Imbalance from a Normal Subject over 7.3 s.

Prior to export for display and surface data interpolation, the resulting point cloud data were automatically allocated into one of twenty transverse sections above the normalised reference plane to further amplify volumetric differences between the sagittal sections. A number of third party surface topography interpolation and display packages (Surfer 8 © and Voxler ©, Golden Software Inc.) are currently being investigated for suitability. Fig. 7 depicts the resulting Voxler © output for frame 45 of a 150 frame capture of the subject's back. Further work is being undertaken to use the results obtained to develop numerical measures to describe volumetric asymmetries.

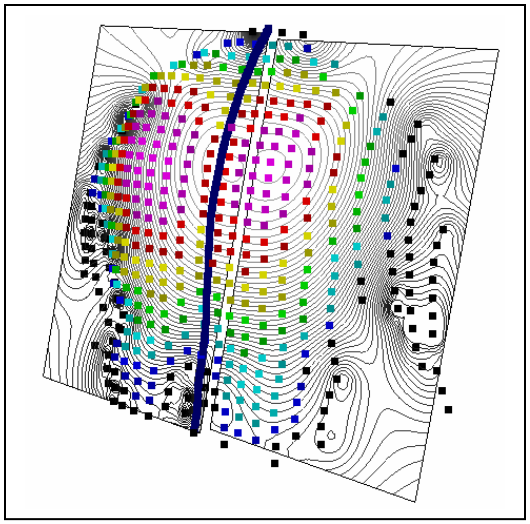

Fig 7. Voxler© Data and Contour Image - Frame 45

2.3 Range of Motion Data Processing Range of motion data were captured from the same subject using common marker placements by switching off the point array projector and switching on the strobes (in the blue spectra) of the three surface capture cameras to improve the reconstruction accuracy of more rapidly moving markers within the measurement volume. Fig. 8 depicts the display of markers in three dimensional space and Fig. 9 a graphical sample of the angle subtended between C7/T1, the central spinous process marker and the marker adjacent to the PSIS over 2000 frames (33 s). The impact of skin movement of the markers on results will be considered as part of the final study.

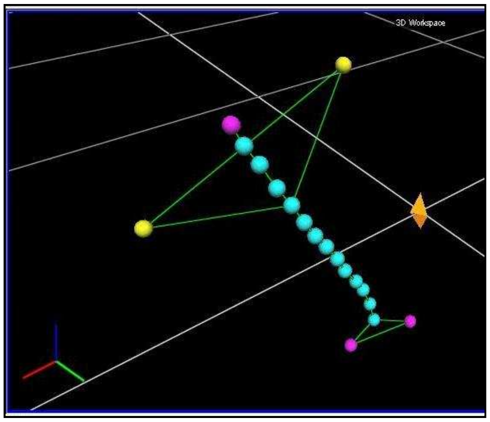

Fig. 8. Markers Single Fame

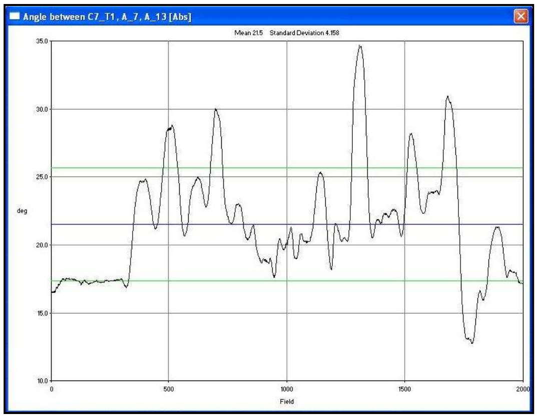

Fig. 9. Range of Motion Angles

3. Conclusion Development of the apparatus and supporting algorithms continues with the goal of producing a tool to quantify and express changes in back surface shape and the range of motion during a clinical session. The resulting data are hoped to form the basis of a useful clinical study.

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