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Validating an imaging and analysis system for assessing torso deformities

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Abstract

We present the results of the numeric and functional validation of an imaging and analysis system used for assessing human torsos for deformities such as scoliosis. The system comprises of image acquisition, image reconstruction, and shape analysis components. The numeric validation procedure consists of assessing the accuracy of reconstruction of the system using inanimate models (a calibration box and a mannequin). The functional validation involves determining the system's response to variations in shape caused by sway and breathing, and evaluating the variability of a clinically relevant index, the Cosmetic Score, from multiple scans of scoliosis and non-scoliosis volunteers. Results show that the reconstruction accuracy of the system is 1.16 ± 1.04 mm. This is better than the required accuracy for monitoring scoliosis of 2 mm. The system is robust to shape variations caused by sway and breathing and shows limited variability to the Cosmetic Score.

Keywords: 3D surface measurement; Laser digitizer; Non-invasive measurement; Scoliosis; Torso imaging; Trunk asymmetry

1. Introduction

Scoliosis is a condition that causes an abnormal alignment of the spine and a deformed torso shape. As an evolving condition, it is essential to monitor scoliosis to ensure that the chosen course of treatment is adapted to the current state of the deformity. Traditional methods of assessing scoliosis focused on the internal deformity of the spine and not on the external shape of the torso. This led to the development of radiographic indices of torso asymmetry such as the Cobb angle [1] and frequent use of invasive techniques including radiography to monitor scoliosis. However, the cumulative effect of ionization due to frequent use of radiographs was linked to an increased risk of cancer [2]. To reduce this risk, scoliosis clinics decreased the rate at which radiographs are taken to about twice a year, a rate some researchers think is inadequate for monitoring the evolution of scoliosis [3].

The desire for more frequent monitoring of scoliosis led researchers to think of ways of predicting the internal alignment of the spine from the shape of the torso [4–7]. Several surface topographic analysis systems were developed based on Moiré fringes [8,9], raster-stereography [10] and optics (such as the integrated shape imaging system (ISIS) [11,12], the Quantec system [6,13] and the INSPECK system (INSPECK Inc., Montreal, Quebec, Canada) [3]), to supplement radiographs. Statistics, machine learning, and artificial intelligence tools were applied to torso images to: (1) assess changes in torso shape and symmetry; (2) classify scoliosis; and (3) predict the internal alignment of the spine. These applications yielded mixed results partly due to the technical limitations of the torso imaging systems used [3] and partly because torso shape is influenced by spine shape, rib shape, muscle alignment, body fat, and skin characteristics in a largely undefined and changing manner which varies from one person to another [6,14,15].

For many scoliosis patients and their families, the primary purpose of treatment is to improve torso appearance with its attendant social and psychological concerns. This realization also encouraged the regular use of torso images in the clinical assessment and monitoring of scoliosis patients [6,14] and to the development of techniques that assessed changes in back shape over time without recourse to the alignment of the spine such as *difference mapping* [16].

Recent years have seen improvements in the available technology for torso topography imaging in terms of speed,

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resolution, and capacity, resulting in a renewed interest in surface measurement for the follow-up of scoliosis patients [3]. Surface topography has been extended from the back to the whole trunk [7,14], resulting in a significantly improved correlation between the indices of torso asymmetry and spinal alignment (compared to what was obtainable from back surface topography).

Scoliosis occurs in 2–4% of the population and only a fraction of scoliosis patients receive an extensive follow-up at scoliosis clinics [3]. The relatively few patients who receive treatment present varied external manifestations. Thus, it is often difficult to obtain datasets of the various manifestations of scoliosis that are large enough for statistically significant analysis from the databases of individual scoliosis clinics. With the increasing availability of full torso topographic imaging systems, it is now possible to create large datasets of full torso scans from the combined databases of several scoliosis clinics. However, as these systems were developed independently, assessing their accuracy, understanding their variability to clinically relevant indicators of torso deformity, and understanding their strengths and weaknesses is a necessary step in this process.

In this study, we consider the task of validating an imaging and analysis system for assessing human torsos for deformities such as scoliosis for its numeric fidelity and functional utility. The system comprises of image acquisition, image reconstruction, and shape analysis components. The numeric validation procedure consists of assessing the accuracy of reconstruction of the system using inanimate models. The functional validation procedure evaluates the system's response to variations in shape due to sway and breathing, and determines the variability of a clinically relevant index, the Cosmetic Score [17], from scans of volunteers with and without scoliosis.

2. Materials and methods

2.1. The torso imaging system

The imaging system used to capture the torso images used in this paper consists of a rotating positioning platform and two MINOLTA VIVID 700 laser digitizers. The details of the operation of the imaging system are described elsewhere [18,19]. Briefly, obtaining a complete model of the human torso consists of two steps: obtaining several partial views of the torso surface (in a way that ensures that every part of the surface is covered by at least one view) and merging the partial views by spline interpolation [18] to obtain the reconstructed surface.

We carried out experiments to determine the optimum configuration for imaging stationary objects using 20 scans of a calibration box from four and six partial views. In each position, the object was 210 mm away from the digitizer. We observed that though the scans obtained using four and six partial views were indistinguishable, the six-partial-view configuration took 50% longer for image acquisition. Thus, we adopted the four-partial-view configuration to minimize the acquisition time and thus reduce the effect of sway and breathing [15]. Fig. 1 shows a MINOLTA VIVID 700 digitizer and a mannequin (modelled from the torso surface of an actual scoliosis patient). Fig. 2 shows the relative positions of the digitizer vis-à-vis the

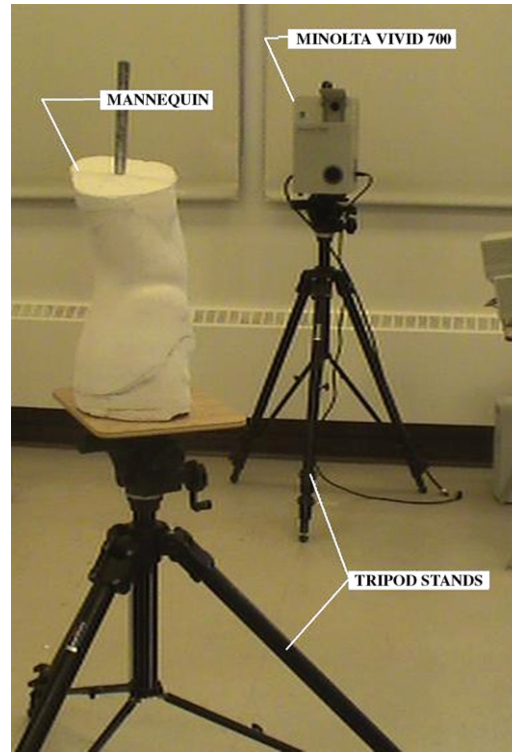

Fig. 1. A MINOLTA VIVID 700 3D surface digitizer and a mannequin.

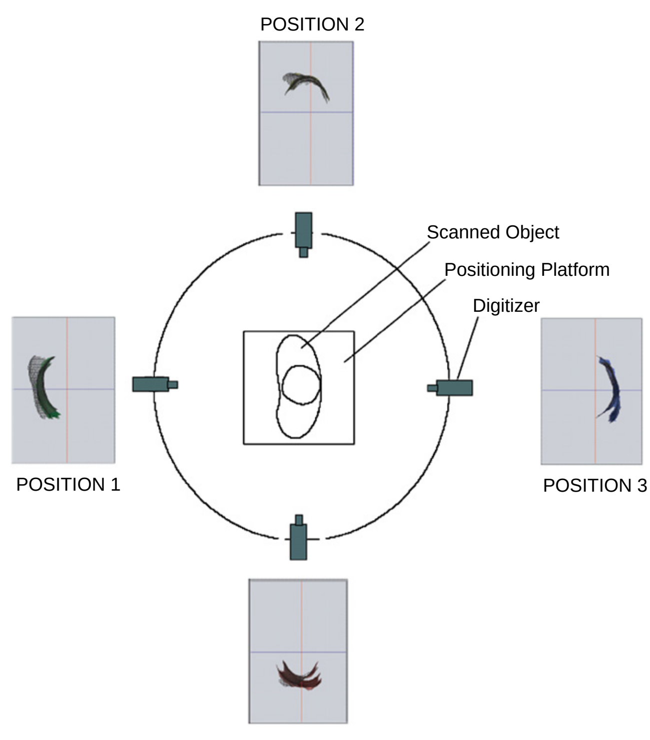

Fig. 2. The four positions of the digitizer in the torso imaging system.