PRELIMINARY ERROR ANALYSIS IN A COMMERCIAL WHOLE-BODY LASER SCANNER

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INTRODUCTION

Anthropometry measures the human form, motion, forces and working capacity associated with motion. The study of anthropometry has served an important role in the quantification of human interaction with working environments since 19th century industrialization [1]. However, the study of anthropometry has changed significantly in the last two decades due to the increasing complexity of design, expanding applications and the ease of data collection. With respect to ergonomics, anthropometry primarily consisted of linear and circumferential measurements of human subjects obtained using manual measurement instrumentation such as measuring tapes and anthropometers. Segment and total body volumes utilized manual displacement and hydrostatic strategies for measurement [2]. With the emergence of laser imaging in the garment industry, the development of scanning technology as a means of rapidly collecting detailed anthropometric measurements with more sophisticated measurement apparatus became a possibility. Laser imaging also provides an alternative to manual measurement in the collection of general anthropometric surveys focused on the traditional length and girth measures [3]. From a health application perspective, laser imaging has been used to collect one- and two-dimensional measurements combined into a health index proven to be predictive of health status [4]. However, there may be other health-related benefits for which scanned measures of body mass, volume and shape would be useful.

The technology under evaluation in this study was a commercial whole body laser scanner, for which a series of validation studies was designed. Specifically, a series of scans was acquired in a pilot sample of people as well as a series of scans on regular shaped objects to allow for a more detailed analysis of measurement. The purpose of this preliminary project is to validate a laser scanner for length, girth, and volumetric measurements. The imaging apparatus investigated employs 670 nm light reflected off of the scanned subject recorded by imaging units in each corner of the scanner. The eight resulting images are merged to create to a single text file containing three-dimensional coordinates, called point cloud files.

METHODS

Visual observation of prior human scan data using proprietary software developed by the scanner manufacturer demonstrated sagittal view plane distortion below the knees and above shoulders on human subjects gathered in prior experiments. Based on this observation, a series of measurements of object diameter was collected using customized software developed for this project. A 25.4 cm diameter, 1.8 m tall cardboard cylinder shown in Figure 1 was coated in white paper and placed into the scanner. The scan took approximately one minute.

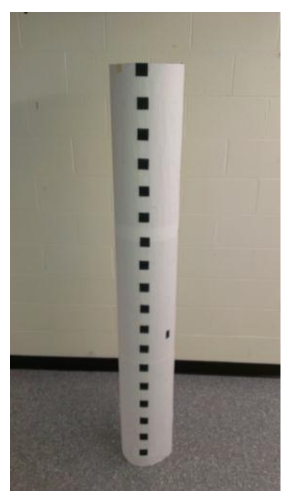

Figure 1: Scanned cylinder with landmarks

Manual and scanned measurements were taken at 10 cm increments along the vertical height of the cylinder in the X-axis (medial-lateral) and Z-axis (anterior-posterior) directions. Manual measurements of these diameters were taken in each of the directions at each landmark using a standard Holtain™ anthropometer. Landmarks were identified by 3.8 cm square, light-absorbing squares along the length of the tube in Y-axis (superior-inferior) and were represented by gaps in the cloud output files.

ANALYSIS

The differences between the scan-extracted measurements and the manual measurements were calculated to determine error values for both the X and Z directions. A 2nd order polynomial regression was used to model the error of the scan-extracted measurements separately for each plane, with respect to the Y-axis height. The differences between the polynomial model and the error values were calculated at each Y-axis increment, in both the X and Z directions in order to correct the systematic error. The Bland-Altman statistical test for agreement was applied to each axis, such that the 95% confidence interval of agreement could be determined. A Pearson Product Moment Correlation was performed on the corrected residual data with respect to Y-position, for both X and Z directions.

RESULTS

The overall mean errors (SD) were 0.02 (0.43) cm and 0.96 (1.15) cm for the X and Z directions, respectively. As expected, the errors systematically increased near the top and bottom (vertical) thresholds of the scan range, as shown in Figure 2.

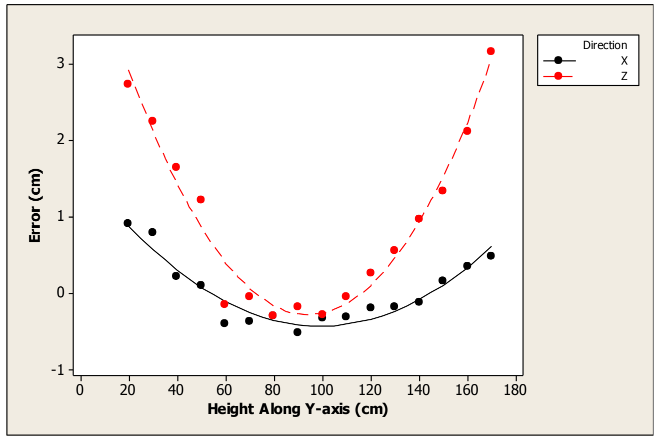

Figure 2: X and Z length errors with respect to the vertical position.

From the graphs it can be shown that Z-axis error is greater in magnitude than the X-axis error. Equations (1) and (2) describe the parabolic functions that model the systematic error in each of the X and Z directions.

$$err_x=1.63-0.0414y+0.000208y^2 \quad (1)$$

$$err_z=4.88-0.109y+0.000581y^2 \quad (2)$$

The model equations were then used to correct for the recorded diameter errors which reduced overall mean errors to less than 0.1 cm with standard deviations of 0.13 cm and 0.21 cm for the X and Z axes, respectively. After correcting for the systematic error (Bland-Altman method), the 95% confidence interval for the limits of agreement between the true and measured diameters was determined to be 0.25 and 0.42 cm for the X and Z-axes, respectively. The systematic error-corrected graphs can be seen in Figure 3 for X and Z-axis measurements. This figure demonstrates little or no perceivable systematic pattern (Corrected X to Y: r=0.034; Corrected Z to Y: r=-0.110).

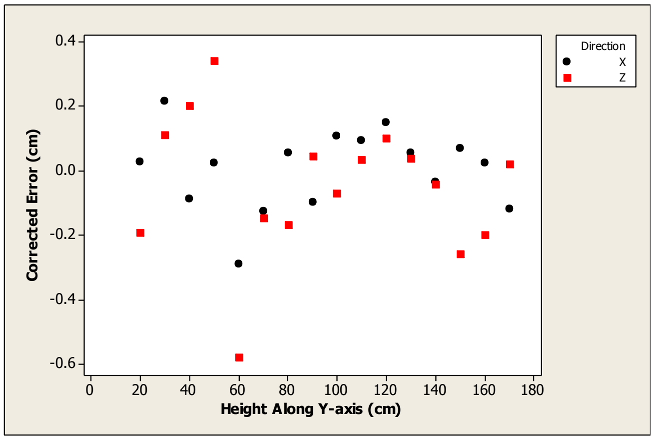

Figure 3: X and Z length errors with respect to the vertical position corrected for the systematic error.

DISCUSSION

The results from this study demonstrate that minor measurement errors associated with the laser scanner can be identified and corrected to improve the overall measurement performance of the device. The object used in the project, although of regular shape, is representative of some circumferential measures of the human, such as those found in the thigh and waist regions. After error correction, the current instrument meets the general requirement suggested by ANSUR [5] for comparable length measurements (approximately 0.6 cm).

While the current laser scanner creates systematic error, the compensation performed above corrects for the systematic error and yields an acceptable a magnitude of random error suitable for the intended applications. One possible cause of this systematic error may be the small height of the calibration field. A solution to this factor would be to expand the area of the calibration field. In addition to linear measures, the current research focus requires volumetric and circumferential measurements of the whole body and various body segments. Given the results presented above, these measurements should be achievable to within an acceptable level of error.

This study is quite preliminary and further study will involve validating over a range of cylinder diameters, in order to correct for errors within the entire scan volume.

Given the application, and requirement for segmental volume measurement, work has been done applying the corrections seen above to segmental and total body volume measurements. This work will be expanded to a full-scale volumetric validation on both the scanned cylinder as well as human subjects.

CONCLUSIONS

This preliminary study has demonstrated that the commercial scanner shows promise as a means of rapidly collecting a variety of anthropometric measurements and leads to the following conclusions.

1. The error values after compensation for systematic distortion are within the mean allowable differences between measurers in prior anthropometric studies for most anthropometric measurements.
2. While compensating for systematic error is possible, refinements in the calibration procedure are expected to improve this systematic error. With these changes, post-processing compensation may not be necessary.

Further validation work is ongoing to examine the use of the scanner for volumetric measures of human subjects.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial assistance from EnCana, Unique Solutions, Dartmouth NS and NSERC. The authors also wish to acknowledge the assistance of Ms. Audrey Prayal-Brown, Mr. Joshua Goreham, and Mr. Jinyu Li for the data collection and analysis.

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