Automatic Landmark Identifications for Various Body Shapes

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Keywords: 3D body scan, Body shapes, Landmarks, Anthropometry

A 3D body scan technology has been used for mass customization in the apparel industry. The accuracy of body measurements is very important for apparel manufacturers to develop patterns and sizing systems. However, most automatic body scan methods often show landmark location errors when dealing with nonstandard body figures (Ashdown and Dunne, 2006). The errors nullify the advantage of saving time for automatic body measurement system, and it creates inaccurate body scan measurements. The inaccuracy causes ineffective sizing systems for apparel mass production. The accuracy and consistency of measurements are related to algorithms of the automatic landmark extraction that are usually predefined by 3D body scan developers.

There are three approaches to automatic landmark extraction. The first approach is to identify a landmark by using geometric characteristics of body surfaces around each landmark. The second approach is to use a statistical relationship among landmarks. The third approach is to match individual body figures to a template model. In the first approach, Dekker et al (1999) detected landmarks based on the relation between the surface shape of each body part to other landmarks (Dekker et al, 1999). A limitation of the study (Dekker et al, 1999) was that only the accuracy of sizes was verified rather than the landmark positions. Wang et al. (2003) extracted feature points using fuzzy logic, and the feature points of the human body were extracted from the relation between the surface shape of each body part and other landmarks (Wang et al, 2003). However, Wang et al. (2003) did not verify the accuracy of the feature points because it focused on the generation of a body feature model. Iat-Fai Leong et al. (2007) automatically detected landmarks through image processing and computer geometry by logically and mathematically analyzing feature point definitions (Iat-Fai Leong et al, 2007).

In the second approach, Ben Azouz et al. (2006) used the “learning of spatial relations” among the characteristics of landmarks and body scan data with landmark sets (Ben Azouz et al, 2006). The learned information was formalized into a pair-wise Markov network. Each node on the network corresponding to the landmark position was a random variable. An edge on the network indicated the positional relation between a pair of landmarks. In addition, Ben Azouz et al. (2006) performed statistical inference on the Markov network for positioning landmarks. The study (Ben Azouz et al, 2006) verified the accuracy of the extracted landmarks.

In the third approach, Au and Yuen (1999) recognized features by creating an original feature model. Landmarks were placed on a torso mannequin, and the original feature model is scanned. Then, each individual landmark in the original feature model was compared and matched to the point clouds in the scanned feature (Au and Yuen, 1999). These approaches have both advantages and disadvantages. However, none of them provide consistency of identifying landmarks on various body shapes. The purpose of this study was to provide algorithms of the automatic landmarks identification that are applicable for describing any various body shapes. In this study, algorithms were developed for the automatic identification of the five landmarks of the torso: bust points, underbust, waist, abdomen, and hip.

Methodology and approaches
In this study, a methodology of identifying landmarks was based on the maximum value, the minimum value, the radical slope changes in front view, the silhouettes, and the cross sections. In addition, statistical position of each landmark was used when any distinct geometrical feature and criterion was not identified. Algorithms of the automatic landmark identification were implemented with C++, and the following coordinate system was used: the leftward direction is to be the x-axis; the upward direction, the y-axis; and forward direction, the z-axis. The x, y, z value of a landmark referred to as width location, height location and depth location, respectively.

The automatic landmark identification written in C++ was tested on a data set of various subjects from Size Korea National Sizing Survey. The WB4 body scanner (Cyberware Co. Ltd., USA) was used in this study. The automatically identified landmarks were compared to the manually marked points. The accuracy and consistency of the automatic landmark identification were verified by evaluating both Mean Differences (MD) and Mean Absolute Differences (MAD). The MD was calculated by subtracting the measure of each manually marked point from the measure of each corresponding automatically identified point. A positive (+) MD means that the measure of the automatically identified point is larger. In addition, one-way ANOVA and Duncan test for multiple comparisons were used to verify if there were any MAD value differences among body figure groups in the significance level set at $P \leq 0.05$ level ($a>b>c$). The MAD of each measurement was compared with the allowable technical errors in the ANSUR Natick/TR-89-044 technical reference (Gordon et al, 1989).

**Results**

**Bust landmark identification:** The height of bust point (=Y axis) was determined as a ‘first point where slop degree change from minus to plus value ($P_{\text{slopc}}$) on the side silhouette (Sil$_s$) from up (armpit height) to down’ ($P_{\text{slopc}}$(Sil$_s$)). The difference in width location was calculated between side silhouette bust point ($P_{\text{slopc}}$(Sil$_s$)) and actual bust point. As a result, the actual bust point was more outward than the side silhouette bust point by 18~35mm. The bust point of obese body type was more outward than that of normal type. Therefore, this study adjusted the width position of the side silhouette bust point to be mean ratio position of ‘distance between bust points’ to ‘bust width’. There were differences in bust height and width position between ‘automatically identified (AI) bust point’ and ‘manually marked (MM) bust point’ by sex and body figure. The MAD of height was less than the allowable error, 10mm according to ANSUR (Gordon CC et al, 1989). The MAD of width was small and much less than that of the non-adjusted bust point of side silhouette point. By the body figures, the width MD was not significantly different among body types. However, the height MAD of overweight was significantly smaller than other body types. This result indicates that bust point location is easily identifiable in overweight.

**Underbust landmark identification:** The underbust point was identified on a sagittal section. Among many sagittal sections, we used a sagittal section (S$_{\text{bust}}$) which passing through the bust point point because the underbust position was clearly revealed at the section and in physical measurement also the underbust point was determined at just under the bust point. There was no significant difference among body shapes in the underbust category. The MAD of height was small and was less than the allowable error 10mm according to ANSUR. This result indicates that the under bust is easily identifiable with high accuracy.

**Waist landmark identification:** There were two ways to define waist landmarks by body scan developers. One was based on “the small of the back point” and the other was based on “statistical mean value of the waist. The two different methods were tested in this study. “The small of the back” was defined as the point where the spine had the largest indent in side view. In the result, “the small of the back point” had no correlation with the waist point. The mean difference was -30.4mm and the standard deviation was 28.1mm. When the statistical mean waist height (y value) was based on ‘mean ratio of waist-crotch
distance to back neck-crotch distance’, the statistic approach of defining waist was more accurate than using “the small of the back point”.

The front silhouette consisted of a set of points with maximum and minimum x-value on each cross section. According to the ISO definition, a waist landmark is the most concave position. However, the concave position was not easily identifiable for various body shapes. Therefore, in this study, first classify the waist shapes by using three points on the front silhouette; point of underbust height (P_{up}), point of middle hip height (P_{down}) and point of the largest distance from the line connecting those two points (P_{concave}).

After the waist classification, two waist shapes were categorized: hourglass waist shapes (X) and rectangular waist shapes (H). The hourglass waist shape (X) had the concave point that was determined as the waist point while the rectangular waist shape (H) did not have any geometrical body surface features around the waist. In this study, two different methods were used for identifying landmarks on waist: ‘waist concave point method’ was used for waist type X (=Hourglass shape) while the ‘mean waist height method’ was for waist type H (= Rectangular shape). When the accuracy was tested separately with two waist types, X and H, the women’s waist type X had height MAD of 4.5mm and waist type H, 7.1mm. The both MAD were less than the allowable error 11mm according to ANSUR.

**Abdomen landmark identification:** The abdomen point has been set at the most forward protruded point between underbust height and hip height. Abdomen point was determined as the most forward prominent point at the front side silhouette similar to the definition of physical measurement. The search range was limited to the statistically possible range, using the ratio of ‘vertical distance from abdomen to crotch’ to ‘vertical distance from back neck to crotch’. The accuracy was tested on two abdomen types; prominent abdomen and obscure abdomen. For the prominent abdomen type, the MD and MAD of height were between 0mm ~ 5mm in the search range. However, for the obscure abdomen type, the MD and MAD were large 0mm ~47mm and the difference of μ ± 2σ range was greater than that of μ ± 1σ range. The allowable error of abdomen height was not listed in ANSUR. According to the allowable error of waist, 11mm, the MAD of prominent abdomen shape was within the allowable error. However, the MAD of obscure abdomen shape was not within the allowable error.

**Hip landmark identification:** The hip point was determined at the most backward prominent point when viewed from the side. We limited the search range to μ ± 3σ of ratio of ‘vertical distance from hip to crotch’ to ‘vertical distance from back neck to crotch’. When the identifying landmark method was tested on the various hip shapes, hip point was easy to find on all bodies because buttock was protruded clearly regardless of body types, and the MD of height was small and less than the ANSUR’s allowable error, 7mm.

**Conclusions and Suggestions**
Landmarks were related to body figure factors: the body weight, the waist shape and the abdomen shape. Each body figure was grouped by body weights (= body figure factor) to identify the landmarks of bust points and under bust. The waist was determined with the waist shape (=body figure factor). The waist landmark was identified with a concave point on the upper body from the front view, and the existence of concave point was different by the waist shapes (e.g. Hourglass shape or Rectangular shape). The abdomen landmark was identified with the most forward protruded point on the abdomen shape from the side view. The existence of the protruded point was different by the abdomen types (e.g. Protrusion type or flat type). The hip landmark was identified with the most backward protruded point from the side view.
The body figures could not be grouped by the hip shapes since all body figures had the same protruded point.

Except unclear landmark definitions in physical methods (ISO 8559), the results showed that our algorithms of defining landmarks were valid for various body shapes. When the accuracy of the developed automatic identification in this study, we found problems of identifying landmark locations were due to unavailable ISO physical landmark definitions for various body shapes. Certain definitions of the physical landmarks could not be applied for all different body shapes. For example, abdomen landmark location was not easy to be identified in obscure abdomen shape. The waist landmark location with a definition, “the small of the back point”, had no correlation with the waist location. Most women’s concave points were found in the range between the under bust height and garment’s waist band height. Therefore, it will be necessary to define landmarks based on body figure factors and body shapes.

Algorithms in this study will be useful for body scan developers to enhance accuracy of the 3D scan data so that apparel manufacturers and researcher can develop consistent sizing systems for various body shapes.

References


