NC STATE UNIVERSITY

JTATM
JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

Volume 4, Issue 1, Summer 2004

Using 3D Scans for Fit Analysis

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ABSTRACT

This research tested the effectiveness of using 3D scans of clothed participants in the fit analysis process. A panel of three expert judges viewed scans of 155 Misses size participants in the best fitting size of a test pant style. They rated 13 fit locations as Acceptable, Marginal or Unacceptable and then gave overall ratings for both front and back views. The ratings for all judges were added together to develop Acceptable, Marginal, and Unacceptable categories for each area and then compared using frequencies, means, and percentages to identify problem fit areas. Ease, line, balance, and set elements of fit were clearly seen on the visualizations of the scans and grain could be evaluated by its effect on silhouette. We concluded that substituting 3D scans for the live fit analysis process in research and industry has potential for 1) recording one single instance of fit that can be rotated and enlarged to view specific areas of analysis, 2) creating databases of scans of a variety of body shapes and sizes wearing a single size (in essence, testing multiple fit models), 3) scanning garments on fit models in multiple poses to evaluate garment/body relationships during natural movements, and 4) holding virtual expert panels where panelists can access the fit session at any location.

Keywords: body scan, 3D data, visualization, fit analysis

Introduction

3D surface scanning technology has evolved as an industrial tool to measure and compare three-dimensional objects at varying stages of assembly for the process of product development. Most industrial product development applications use the scanner with geometric rather than organic shapes. Use of 3D surface scanning technology for the human form is much more difficult. The human body morphology is a complex organic form that can undergo both subtle changes over time, such as posture, weight gain/loss, and large deformations in geometry through movement and changes in body positions. When designing products for the human body, in addition to considering these variations for an individual body, we must also accommodate the variation of shapes across a population.

Work is underway to make mathematical comparisons of measurements from 3D body scans, transferring existing industrial techniques to improve apparel fit (Ashdown, Petrova, Loker, & Cowie, in press; Tahan, Buxton, Ruiz, & Bougourd, 2003). Due to the complexity of the body's geometry, this is a challenging task. However, body scanners offer another immediate benefit to the apparel industry by capturing an accurate 3D representation of a garment's relationship to the body while minimizing visual distractions. Our research has found that the 3D scanner is an effective tool to capture and store critical visual fit information that is more effective than photographs (Douty, 1968) or videotapes (McCulloch, Paal, & Ashdown, 1998) used for body shape analysis and apparel fit analysis by past researchers. By scanning study participants wearing a basic ready-to-wear style of pant and viewing the scans from a variety of positions using rotation and zooming, we have visually analyzed fit to identify problem areas in a pattern design for its target market.

Cost and Size of Scanners

Scanning technology is rapidly becoming more affordable. Current scanners differ in price range (US $40,000 - 410,000), as well as resolution (1 - 8 mm) and speed (3 - 15 seconds). Most of the current scanners on the market use laser stripe projection while others use projection of patterned light or stereo photogrammetry (Daanen & van de Water, 1998). With laser stripe projection, narrow bands of laser light are projected on the body and the image is captured by a set of cameras. The lasers travel from the top of the scanner down to the base, projecting light along the whole body while the cameras capture data from the area illuminated by the laser. These data are saved as a set of X, Y, Z coordinates which are then visualized on a computer screen. The scanner software patches together the different camera views to represent a single object. The software triangulates the data points and visualizes the image as a three-dimensional surface on the screen. The speed of the movement of the lasers as well as the number of cameras determines the number of points captured and quality of the scanned image. Scanners utilize anywhere from 2 to 16 cameras. Those with more cameras are able to capture a large amount of information about the subject including colors and textures in addition to form. The quality of the scanned image is also affected by the sophistication of the software that aligns the different camera views. Software can be used to remove redundant points where different camera views overlap and to 'patch' areas where the camera has missed data points, all leading to a more complete smoothed visualization of the scanned body.

Scanner technology was designed to maximize the quality of scans of minimally clothed subjects. The optimal position for scanning is a modified anthropometric position with feet positioned about 30 cm apart and with arms abducted from the body. Other positions often result in holes or missing data due to some portion of the body obscuring another area such as under the arms, or areas where the camera cannot record data, such as surfaces parallel to the floor. Surfaces such as hair and dark, textured clothing also erode the quality of the scan by scattering the light and preventing the cameras from capturing a complete set of data points.

Body Scan Applications

Three-dimensional body scanning has a multitude of uses both within and outside the apparel industry. Outside the industry, computer animators have been using scanned images for animated movies such as *Final Fantasy* (Robertson, 2001), for computer generated special effects such as those in the *Matrix* (Ayotte, 2003), and for generating digital images of famous personalities to use as stars in computer games (Chezzi, 2004). Designers working on products to accommodate the human body such as workspaces or car seats have used scanning to ergonomically shape the final design (Cerney, 2003). Physicians have used 3D surface scans to track body changes, recording accurate "before" and "after" states (Vannier, Pilgram, Bhatia, Brunsden, & Commean, 1991).

Within the apparel industry, body scanning promises a multitude of opportunities. Business-to-business (B2B) companies such as Bodymetrics (http://www.bodymetrics.com/) and My Virtual Model (MVM, http://myvirtualmodel.com/) are teaming up with retailers to create virtual models of customers, which consumers can manipulate to mirror their own bodies. Consumers can then try clothing on their model online. The current, widely available technology developed by MVM creates models from manual measurements but the concept is to eventually try clothing on actual scan data. Other companies such as Yourfit.com allow consumers to enter their measurements (or eventually their scans) to predict appropriate sizes across different brand-name apparel (Abend, 2001).

In B2B situations, companies including PAD Systems Technologies (http://www.padsystem.com/), Browzwear (http://www.browzwear.com/), and Optitex (http://www.optitex.com/) are developing programs designed to work with a two dimensional pattern draped over an avatar created from scan data. Some programs under development allow the patterns to be manipulated in three dimensions on the screen and then to be flattened back to a two-dimensional pattern for production. Groups such as Osma Engineering S.A.S. offer a collection of software packages that allows the designer to use a scan to gather automatic measurements, translate those measurements into a custom pattern, virtually "stitch" the pattern together, try it on a virtual model, make modifications to the pattern, flatten it back to two dimensions, make a marker, and send it for production (DesMarteau & Speer, 2004).

New technologies allow the designer or product developer work digitally as long as possible so that patterns can be modified up to the last minute and manufactured to changing specifications to accommodate consumer preferences and the ever-changing market. Scanning can contribute to this process by creating one or many virtual consumers or fit models within the flexibility of a digital environment.

Fit Analysis

Analysis of the fit of clothing is a complex process in which the relationship between the human body and clothing is assessed to judge how well the clothing conforms to a set of requirements. These requirements or elements of fit are commonly categorized as ease, line, grain, balance and set (Erwin, Kinchen, & Peters, 1979). A well-fitted garment is a garment that hangs smoothly and evenly on the body, with no pulls or distortion of the fabric, straight seams, pleasing proportions, no gaping, no constriction of the body, and adequate ease for movement. Hems are parallel to the floor unless otherwise intended, and the garment armscyes and crotch do not constrict the body.

Expert panels are frequently used in fit analysis research and other types of research to assess complex issues when objective measures cannot be found. The concept behind the use of expert panels is that the human senses used as a testing instrument can identify and process complex stimuli more effectively than other measurement devices, particularly when complex forms of pattern recognition are needed (Leibowitz & Post, 1982). Fit analysis of apparel has been effectively conducted by panels of trained judges to provide reliable and valid data (Choi & Ashdown, 2002). In addition to averaging responses over the group of judges, discussion and negotiation of ratings can improve reliability as complex visual analysis decisions are made.

In industry, fit analysis is often conducted with a single fit model for each brand in a base size. A team of pattern makers and designers view a sample garment on the fit model and judge its effectiveness, make changes, and approve the garment for development of a production pattern. The team acts similarly to the expert panel of judges in fit analysis research. With off-shore production, these collaborative sessions are more difficult to stage due to remote location of pattern making or assembly. Two advances in technology have aided fit analysis recently. Fit model "doubles", dress forms made from body scans of the fit model, allow sample and production garments to be tested at remote sites. Systems, such as Alva products (http://www.alvaproducts.com/) take digital images of a garment on a form in order to discuss fit by videoconferencing these images back to a home office. The resolution of these images is not ideal and video conferencing by satellite or the Internet further reduces the clarity of the images. However, neither of these new methods provides a fit analysis that can use multiple fit models representative of the target market population's variation in body shape and measurements.

This research tested the effectiveness of using 3D scans of clothed participants in the fit analysis process. Substituting 3D scans for the live fit analysis process in research and industry has the potential for 1) recording one single instance of fit that can be rotated and enlarged in specific areas for analysis, 2) creating databases of scans of people with differing body shapes and sizes wearing a single style (in essence, testing multiple fit models), 3) scanning garments on fit models in multiple poses to evaluate garment/body relationships during natural movements, and 4) holding virtual expert panels where panelists can access the fit session from any location.

Method

This research is part of an ongoing project using the body scanner to improve an existing apparel sizing system based on target market 3D scan data. Using multiple measurements derived from scan data, we are evaluating how the size range, measurement specifications, and grading rules can be improved to better accommodate a set of pants designed for a specific female target market. A Tecmath VITUS/smart 3D body scanner with eight cameras and four eye-safe laser light sources was used to capture approximately 300,000 spatial data points per scan for each participant in the study. Two hundred and five female participants were selected to fit our industry partner's target market of 34-55 year old women in Misses 4 - 16 and Women's 14 - 24 sizes. Participants were scanned twice, once in minimal clothing and a second time in the best-fitting size of test pants, selected by the researcher to fit at the hip. Foam strips were used to hold the pants up at the waistband if necessary to maintain the correct relationship of the pants to the body. The Polyworks software suite from Innovmetric was used to merge, align, and clean the scan data and to provide 3D visualizations of the scan data.

Figure 1. Front and back views of two study participants rated with Acceptable and Unacceptable fit.

In order to understand the objective data from the scans and to make recommendations on how to design a better sizing system, it was necessary to identify the pants and the portions of the pants that fit well and those that fit poorly. We observed that the visualization of the scans of the subjects wearing the pants clearly showed classic stress folds, compression of the body, and distorted areas of the silhouette that identify areas of misfit (Figure 1). The scans could be rotated to any view of the body on a horizontal axis—back, side, or front—as well as on a vertical axis to view from a different angle (Figure 2). In addition, the rater could zoom to enlarge a specific location of interest. The stress folds show the fit of the pants clearly in Figure 3. The pants are somewhat tight at the abdomen and loose at the waist.

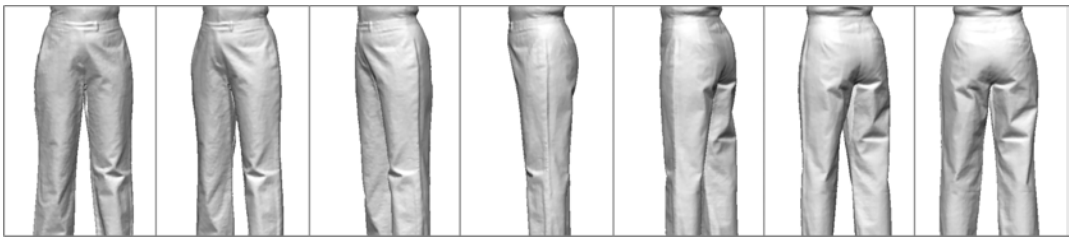

Figure 2. Rotated pant scans.

Figure 3. Selective zoom of pant scan.

After scanning the participants, scan data were processed to create smoothed 3D visualizations. Scan files were then merged to create one file with the minimally clothed scan represented next to the scan of the participant in the best-fitting size of test pants. A database was developed in Microsoft Access to allow each expert to view the merged scans and rate 13 critical fit locations and overall front and back ratings (Figure 4). We designed a process involving a panel of three expert judges to assess the fit of the pants using the scans. The experts averaged over 20 years of experience in judging fit in various capacities; theatrical costuming, teaching fit, evaluating the fit of student projects, and fit research.

Figure 4. Screen-shot of rating database and scan visualizations.

Twenty-six study participants were scanned in more than one size of pants if it seemed there was a question about which size fit best at the hip. The expert panel reviewed the 3D visualizations of these participants in the different sizes in which they were scanned and determined the best fit size to use for further analysis. While the better fit may have been difficult to determine at the time of the data collection, viewing the scans side by side usually resulted in an easy decision between the sizes. The scans not selected as the best fit for these participants were removed from future use in the study. In addition, two participants' scans were removed from further analysis at this time because they had extreme right/left body asymmetry which was atypical of the overall sample, leaving a sample of 203 scans. The sample included 155 Misses size participants across seven sizes and 48 Women's size participants across six sizes. There were less then 10 participants in each of the Women's sizes 18 through 24, insufficient numbers to draw conclusions for the localized areas. All further analysis will discuss only the Misses' sample.

Each of the three experts individually rated the 155 Misses participant scan visualizations at 13 fit locations as Acceptable (1), Marginal (0), or Unacceptable (-1) and then gave overall ratings for both front and back views. These ratings were compiled and ratings were flagged for further review when the experts rated at both extremes of the scale, i.e., one expert rated the fit Acceptable and a second expert rated the fit Unacceptable for the same area.

The three experts met as a group to review the scans with these ratings of extreme disagreement. The experts reviewed and discussed the ratings until they agreed on a final set of three ratings (one for each judge) that were within one point of one another (i.e., -1, 0, 0 instead of -1, 0, 1). Ratings were tabulated for the three judges resulting in a score ranging from –3 (all reviewers rated the area as Unacceptable) to 3 (all reviewers rated the area as Acceptable) for each of the 13 fit locations and for front and back overall fit. Unacceptable, Marginal, and Acceptable rating categories were calculated as follows: -3 to –1 = Unacceptable, 0 and 1 = Marginal, 2 and 3 = Acceptable. This rating scale is used in all further analysis.

Results

The three expert judges found the visual analysis process fascinating and effective. The technology enabled them to see such a large number of scans within a short period of time with easy access and reaccess for comparison, dramatically illustrating the breadth of variations in size, shape, and asymmetry of the human body. The ability to rotate the scans for a variety of views and to compare an individual participant's scan with pants to her scan with minimal clothing proved to be a very effective process to evaluate fit. The ability to zoom in to examine an area in detail made it possible to resolve any questions we had about the meaning of a stress fold or compression area. The electronic rating form was on the same screen with the scans, making the rating process easy initially and during panel discussions, reducing rating errors.

Means and standard deviations of the visual ratings for the 155 Misses scans were calculated and each scan was placed into an Acceptable, Marginal, or Unacceptable category for the 13 fit locations and the overall front and back based on the combined ratings of the experts (See Table 1). For example, for the overall front view, the mean rating score of the scans in the Misses size target market fell in the marginal rating category (*M* = 0.90, *SD* = 1.95). For the overall back view, the mean rating score of the Misses size target market was also in the marginal rating category but fell closer to unacceptable (*M* = 0.15, *SD* = 1.61). Table 1 also presents a count of the scans rated Acceptable, Marginal, and Unacceptable arranged in anatomical order (from waist down) followed by the overall front and overall back ratings.

Table 1
Fit Rating Summary by Area for Misses Pant Scans (N = 155)

	Score[a]		Count within Rating Category[b]		
	M	*SD*	Acceptable	Marginal	Unacceptable
Waist Front	0.26	2.22	58	36	61
Waist Back	0.69	2.16	79	27	49
Waist Placement Front	1.84	1.07	123	23	9
Waist Placement Back	1.41	1.52	91	42	22
Abdomen Front	1.05	1.81	78	42	35
Abdomen Back	1.34	1.49	78	60	17
Hip Front	2.22	1.36	126	16	13
Hip Back	1.56	1.53	99	34	22
Crotch Front	1.28	1.35	77	58	20
Crotch Back	-0.66	1.50	13	51	91
Below Buttocks	1.06	1.54	64	68	23
Thigh Front	2.28	1.13	134	13	8
Thigh Back	2.36	1.24	134	10	11
Overall Front	0.90	1.95	69	47	39
Overall Back	0.15	1.61	35	71	49

Note . Ratings made by three person expert panel. Individual ratings: -1 = Unacceptable, 0 = Marginal, 1 = Acceptable.

[a]Score calculated as the total of the 3 experts' ratings at the individual area. Possible range: -3 to 3.

[b]Fit ratings determined from score: -3 to -1 = Unacceptable, 0 & 1 = Marginal, 2 & 3 = Acceptable.

Figure 5 plots the same data arranged on order of fit ratings (from worse fitted areas to better fitted areas) to aid in identifying areas that fit most participants, such as the front waist placement, hip front, and thigh front and back, and the areas of more frequent misfit, such as waist front and back, crotch, and overall back. Hip ratings indicated acceptable hip fit for a majority of participants, which was to be expected since the pants were selected based on the fit at the hip. The crotch back was clearly the worst rated area indicating a general pattern-making problem for this style that was very obvious during the visual analysis. The relatively poor ratings for the overall back category compared to overall front were also due to the misfit in the crotch back. The waist front and back ratings indicated that the pants fit less than half of the participants acceptably being either too large or too small. On the other hand, fit at the thigh was rated high for most participants. Following these analyses presented in Table 1 and Figure 5, the 3D scans can be reviewed again to visually explore the Acceptable, Marginal, and Unacceptable categories for critical pattern making problems that would provide better fit for more of the target market. Then, base pattern adjustments can be made accordingly.

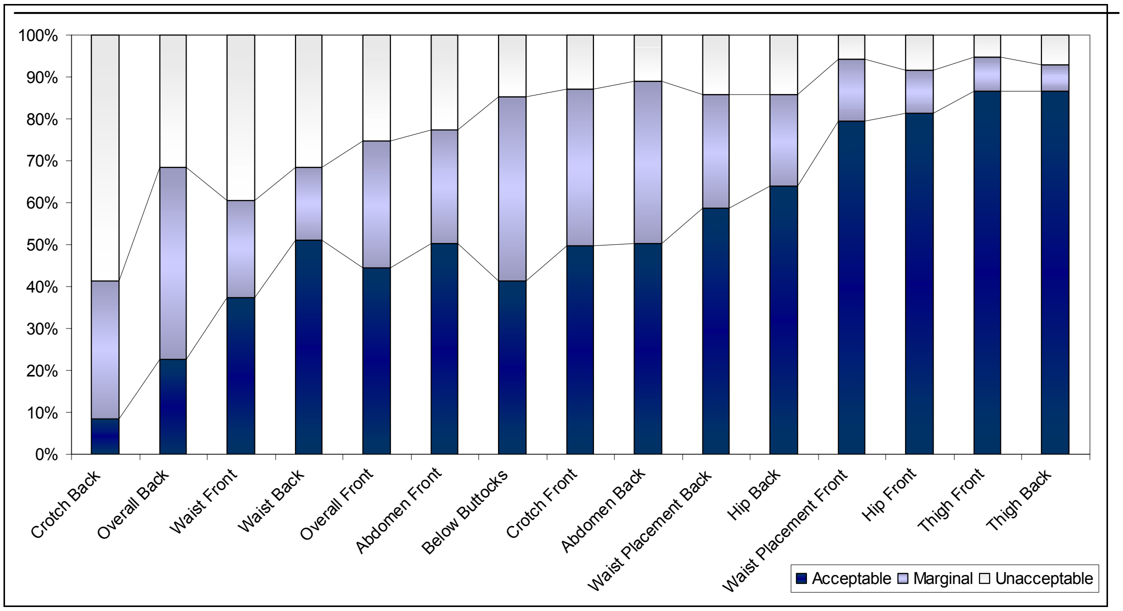

Figure 5. Percent of participants in rating categories by body location.

Figure 6 displays merged fit ratings for the participants in the Misses group by percentage in size category. Ratings were calculated by averaging the front and back ratings and then assigning each set of ratings a fit category. This analysis shows that there are more Acceptable fitting pant waists in sizes 4 and 6 and a larger number of Marginal and Unacceptable ratings for the waist in sizes 12, 14, and 16. The results are similar for the abdomen. These results identify the size categories where the sizing system can be improved.

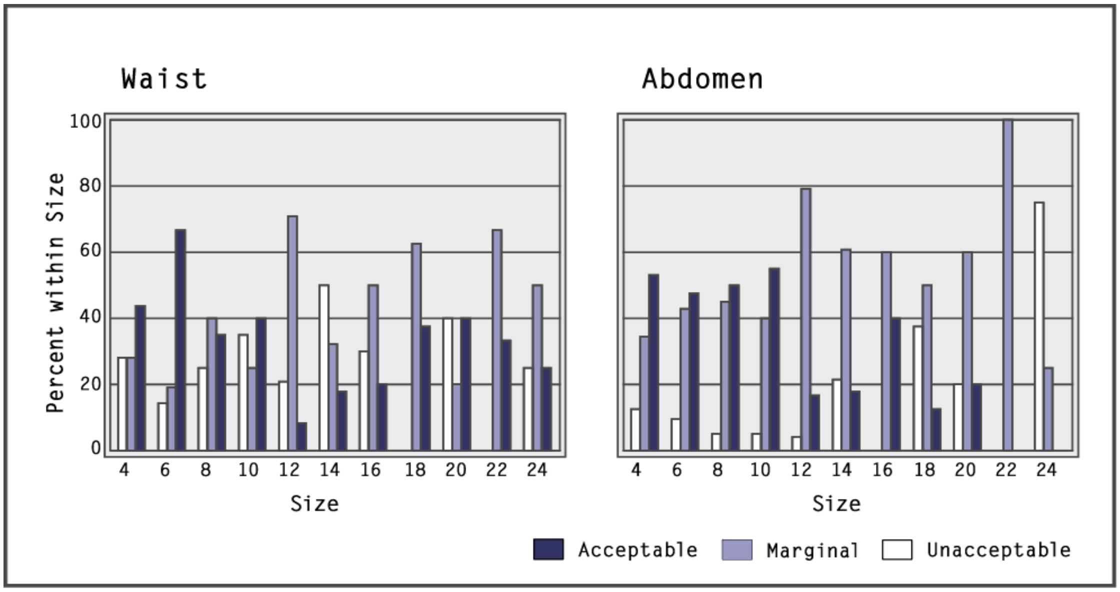

Figure 6. Percent of participants in rating categories (merged front and back) by size.

In summary, visual analysis of body scans was effectively used to organize scans into three fit categories. These categories were then used to identify areas of critical fit issues for the sample as a whole and for individual sizes. The digital nature of the scans can also provide visual confirmation and exploration following numerical calculations of fit problems.

Discussion, Conclusion, and Further Study

Visual analysis of fit using 3D scans was similar in many ways to fit analysis with a live fit model but with some extra benefits. Stress folds were clearly visible and subtleties of the silhouette of the garment on the body were easy to identify. Color, texture, and background distractions were eliminated and it was easier to focus on only the fit issues. In addition, being able to rotate the figure made it possible to view stress folds from all vantage points as they fell around the body. It was also advantageous to be able to view the minimally clothed body simultaneously with the pants scan to identify where the pants were compressing the body and determine body configuration factors contributing to fit problems. The fit judges could note body landmarks such as the location of the fullest part of the thigh or abdomen, and body angles such as the tilt of the hips, by comparing the body scan while assessing pant fit. Body asymmetries, lordosis or kyphosis of the spine, and one hip higher than the other were also clear in the body scans. An understanding of these body variations highlighted the interactions of clothing and body that created the visible areas of misfit in the pants.

Ease, line, balance, and set, four of the five elements of fit, can be seen in body scans and the fifth, grain, can be evaluated by its effect on silhouette. Some issues related to the ease of garments are clear in the scan or by comparing the minimally clothed scan to the clothed scan. Tightness can be assumed by looking at areas where the body is compressed and areas of looseness can be seen through analysis of folds in the fabric and by comparing the clothed to the unclothed body. Mathematical comparisons of measurements from the two scans (clothed and minimally clothed) are the central focus of our research and these can be used to calculate ease values, providing a range of values that appear to correlate to the Acceptable, Marginal, and Unacceptable ratings to some extent. While it is possible to merge the minimally clothed and pants scan so they are aligned with one another and add transparency to the clothed layer in order to see the ease in three dimensions, registration issues arise due to the variations in body position between the two scan instances. Though the visual analysis can be accomplished very effectively using the scan, some dimensions of ease customary to a live fit session cannot be addressed with this tool. Ease can only be thoroughly analyzed through a combination of visual analysis, manipulating the garment by pinching and folding the fabric of the garment against the body, and asking the wearer or fit model about her perception of the tightness of the garment.

Balance refers to the degree to which the garment hangs evenly from the body in every direction. This can be judged by comparing the silhouette of the garment to the body by rotating the scan so the balance of a garment can be viewed from the top of the figure or from underneath. The set of the garment refers to the way it hangs from the body. A well-set garment will follow the shape of the shoulders or waist and hip area smoothly, with no stress folds or torqued areas; this is clearly visible in the scan images through analysis of stress folds and silhouette.

Line refers to the angle of the seams and other linear elements in the design. Seam lines do not show in a basic scan image. Scanners that have multiple cameras to capture color and texture information along with the shape data will show the seam lines, making line assessments of fit possible. However, the basic scans without color have the advantage of showing the stress folds and silhouette clearly because of the lack of color and surface area information that can hide these features. Grain is not visible in the scans, although the result of an off grain garment would be visible in the silhouette.

The ability to store, retrieve, and endlessly analyze a specific fit using electronically accessed body scan images is something that we have not been able to do with other fit analysis tools. This benefits both researchers and apparel companies by providing a record of the fit that can be compiled into a database, either to record the fit of a particular style or the fit of a style on multiple people. The ability to view a number of people in the same style opens up new possibilities to perfect fit for the ready-to-wear industry where the goal is to fit large numbers of people with few size categories. We also found that 3D scans provided images that clearly showed fit issues for discussion when comparing expert panel ratings with extreme disagreement and helped to clear up discrepancies and validate the data.

Another advantage of 3D scan visualizations in fit analysis is that the fit of the same garment on multiple fit models or target market members can be analyzed by comparing their scans side by side, rotating and zooming as necessary. As software is improved to transform 3D scan data to 2D pattern data, additional possibilities for using visual scan data in pattern development and modification during sample making or custom made-to-measure production will emerge. Digital data is easily accessed at multiple locations and a fit analysis can involve a number of people at the same time or at their convenience. 3D scans can be used to improve communication by providing an exact image for discussion that can be easily transported and does not change over time. Expensive time with fit models can be reduced.

Analysis of fit from 3D body scans could also be used for validation of an improved sizing system. Following this methodology, participants would be fitted into the size garment that fits them the best from the original sizing system, and also from a set of garments created using an improved sizing system. Fit analysis of 3D scans of the participants could be used to assess the overall effectiveness of each sizing system and to compare the fit of garments from the systems on individual subjects. The scans of each subject in the two different garments could be compared side to side.

There is great potential for 3D scans in fit analysis in research and industry. Scan visualizations illustrate with images what statistical comparisons of measurements tell us about fit with numbers. The ability to easily scan and organize a database representing the fit of target market members in specific garment styles will provide information necessary to adjust patterns and sizing systems to better fit our population. Industry methods could be adjusted to add a new level of fit testing by trying the full range of sizes on a set of fit models of different sizes. The technology is available to accurately capture spatial data that when visualized, convey all the complexity of the fit of clothing which can be analyzed and saved for later reference. The method of assessing and rating fit from 3D scans using an expert panel of judges has been successfully demonstrated. As the advantages in using 3D scans for fit analysis are recognized, this powerful tool will contribute greatly to the development of better fitting apparel.

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