How is it that three women at 5'8", 5'6" and 5'9", and weighing 150lb, 135lb and 125lb respectively, can all claim to wear a US size 8? This and many other fitting anomalies are the reality for the modern clothing industry in the United States, where a comprehensive analysis of body shapes and sizes hadn't been conducted for several decades prior to the 1990s.

Turning shape and size research into reality

This lack of research, in addition to the growing practice of vanity sizing - adding inches to clothing to make it appear that a woman wears a size smaller than she actually does - has created a disparity between the clothes available to the consumer and their actual body shapes and sizes.

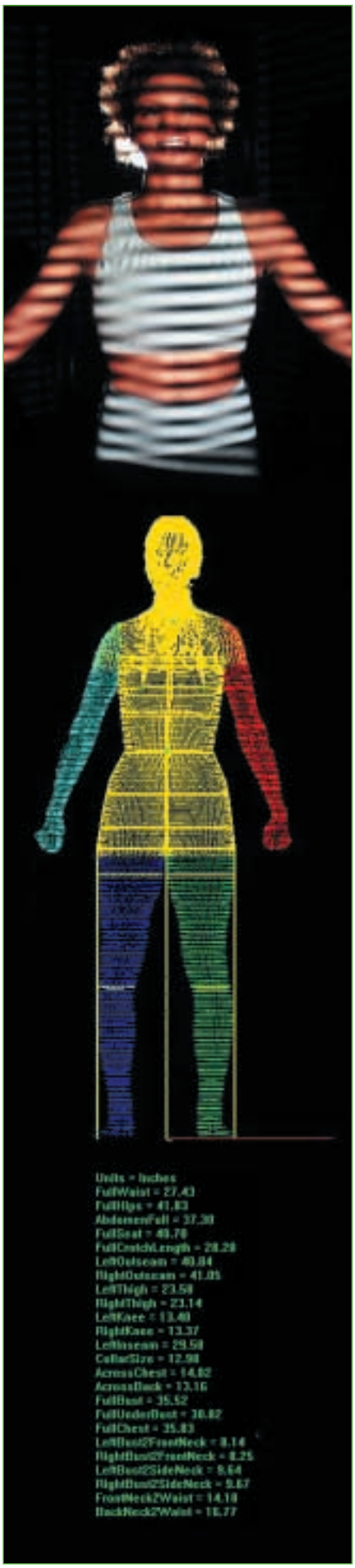
However, help is on the way. (TC)2, the Textile / Clothing Technology Corporation, created as a non-profit industry coalition in 1981, has evolved into a significant resource for the soft goods industry. Amongst its diversified list of services and projects (TC)2 has conducted a comprehensive sizing study of the population of the United States (SizeUSA) in response to studies indicating increased consumer dissatisfaction with apparel fitting.

The survey includes body measurement data on over ten thousand men and women, ages eighteen to sixty-five plus, grouped by gender from six age ranges and four ethnic groups, divided into statistically valid categories. The report contains detailed analyses including average physiques, morphology and comparison with ASTM (American Standard Testing Materials) parameters. Participants were scanned, using (TC)2's proprietary three-dimensional body scan technology, in thirteen locations across the US to provide a cross-section of geographical data. In addition to the scan process, subjects completed a questionnaire to provide demographic, shopping and life-style information to accompany the physical measurement portion of the survey.

Application

A general goal for the apparel industry is mass customisation. In order to remain competitive some sections are driving very hard toward this shift into made-to-measure apparel for the Main Street shopper. Traditionally, tailors have taken the measurements themselves to facilitate their own pattern making methods, but human frailty coupled with mass production techniques has meant that 'tailors' measurements are notoriously inconsistent from one brand to another. It requires underlying technology to facilitate acquiring wholly accurate human body measurements, and extracting the appropriate critical data, so that patterns can be altered for the individual customer.

To ensure universal compliance several technologies are employed by researchers to obtain body measurements, including two-dimensional video silhouettes, laser-based scanning, and white light phase measurement. The first two methods were discarded by (TC)2, laser methods being particularly costly, and white light phase measurement 'profilometry' (PMP) was the chosen approach to accumulate accurate data of the body's surface and to develop consistency in body measurements. The structured light and PMP application is well suited for the role because of the short acquisition time, accuracy and a relatively low cost.



(TC)2 screengrab showing measuring zones.

(TC)2

System design

The Body Measurement System (BMS) was designed to achieve total coverage of the human body. In order to scan the majority of the population the scanning volume was designed to be 1.1m wide by 1.0m deep by 2.0m in height. There are two frontal views with a 60 degree included angle and a straight-on back view. With this configuration there are substantial overlaps between views in areas where detail is needed and minimal overlap on outer edge regions where surfaces are smooth. In order to get adequate height coverage there are six views in total: three upper and three lower. The system design uses six stationary surface sensors that encompass the body by capturing separate segments of the surface. These segments are then combined to form an integrated surface that covers the areas of the body critical to the manufacture of apparel.

Sensor and system software design

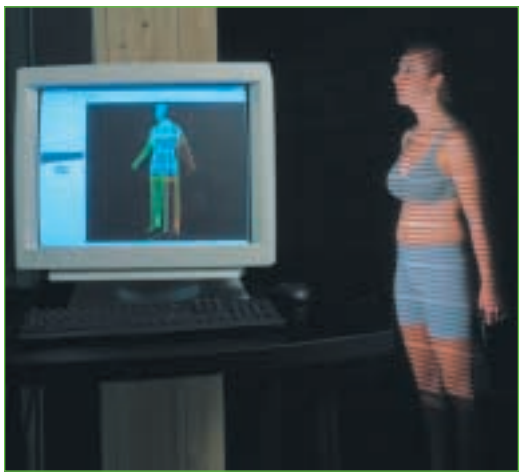
Each sensor consists of a projector and an area-sensing camera, forming a vertical triangulation with the subject's body. The camera and projector are separated by a baseline to form the necessary geometry for mapping points onto the surface of the body. The projector contains a two-dimensional patterned grating that is projected onto the body. The pattern varies in intensity sinusoidally in one direction and is invariant in the perpendicular direction, rather similar to the Sanson-Flamsteed projection in mapping techniques. Both coarse and fine grating patterns are employed. The projected pattern is imaged by an array of cameras equipped with CCDs (charge coupled devices).

The software program was developed in the Microsoft Developer Studio Visual C++ under the Windows NT platform. OpenGL was utilised to create the graphics display tools. The software performs the following functions: graphical user interface, controlling the acquisition sequence, acquiring and storing image buffers, processing acquired images and calculating resulting data points, and displaying graphical output.

The PMP method involves shifting the grating preset distances in the direction of the varying phase and capturing images at each position. A total of four images are taken for each sensor, each with the same amount of phase shift of the projected sinusoidal pattern. Using the four images of the same scene, the phases at each pixel can be determined. The phase is then used to calculate the three-dimensional data points.

Image acquisition

As mentioned above, four images per sensor per grating are acquired. Since there are six sensors in the BMS, a total of 48 images are captured. In order to minimise the capture time, the computer acquires the images using a 'round robin' acquisition scheme. In this manner, all of the images of the first grating position are captured in succession. After each sensor's image is acquired the computer starts shifting the respective grating. When all six sensor images are acquired the sequence is restarted for the next grating position. This process continues until all 24 images have been acquired for the fine grating. The gratings are then adjusted to project the coarse grating. In this manner the critical portion of the scan, which occurs during the fine grating acquisition, is captured within two seconds.



Subject in a (TC)² scanning booth.
(TC)²

The intermediate output of the PMP process is a data cloud for each of the six views. The individual views are combined by knowing the exact orientation of each view in relation to the other five. System calibration is achieved by scanning an object of known size and orientation.

Measurement extraction

With the raw scan data acquired a wealth of three-dimensional geometric information is available. It can be used to make clothing for the scanned individual with a level of fit that would be difficult to achieve with a manual measurement process. However, a data extraction step is necessary to get the essential measurements that can be used to alter the clothing patterns. This process is a fully automated computer function. The automation is desirable because the time required for a computer operator to extract the information using an interactive data analysis tool can be greater than the manual process using a measuring tape. The automated process developed by (TC)² is graphically outlined in the sequence of images beginning with the raw scan data. This data is further processed into a proprietary format that has several advantages over the raw form of the scan data. This proprietary format results from a sequence of processes including:

1. Data filtering, which removes any stray points
2. Segmentation of the body into individual limbs (arm, leg, torso)
3. Smoothing, which removes low-level noise in the scan data
4. Filling, which closes any small gaps in the scan data

5. Compression, on the order of 100:1, to achieve a very 'light' yet fully defining data set.

The primary advantage of using this 'processed' scan data is that it allows for the creation of measurement extraction algorithms, which operate on the data in its raw form. This, in turn, allows the measurement extraction process to be automated.

Automatic pattern alteration using CAD and the Virtual Try-on

Numerous apparel CAD packages have made-to-measure or pattern alteration functions that can be used in concert with the scanner based measurements to create a custom pattern for the customer. The measurements are formatted specifically for the target apparel CAD package so that the input of the data to the system and the output of the made-to-measure pattern, either to a fabric cutter or to a plotter, occurs automatically. Additionally, the possibility now exists for the customer to view the fit and appearance of the made-to-measure garment as a computer simulation (a virtual try-on). The garment is draped on their three-dimensional scan image to approve its fit and appearance before it is made.

Results and effect

Realising that a large number of shoppers would prefer to 'try on and take home,' rather than wait a few days for a customised garment, some brands have capitalised on the data from the SizeUSA survey and have made adjustments in which a statistically greater number of consumers will be able to purchase from graded sizes. Sponsors of SizeUSA include Sara Lee, Russell, Target, Jockey, JCPenney, Levi Strauss, Sears, Liz Claiborne, DuPont and Milliken. As the benefits of such research become apparent, it will be in the interests of all manufacturers to utilise the same data. What is done with the analysis is up to the individual brand owner but those who do not delve into the research may come up short in the marketplace.

The use of SizeUSA in determining just what any size should actually measure is one of the most obvious areas that could benefit the brand owner. In creating a true industry 'standard' size 8, for example, the product developer can produce styles that will improve garment fit across a given demographic and can create both mannequins and virtual models on which to design, develop and communicate the improvements. For the progressive manufacturer, who knows how to capitalise on the benefits of this new technology, the cost will be outweighed by greater productivity. Brand market share will be maintained or grown through education of the customer as to the benefits of the technology. In addition consumers will benefit by the improved understanding of body shape (morphology). The overall aim of SizeUSA is to encourage manufacturers to provide better fitting and, therefore, more comfortable clothing.