Capturing the Shape of a Nation: SizeUK

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ABSTRACT

In 1999 UK Government, universities and industry formed a partnership to pioneer the use of body scanning technology in sizing, custom clothing and virtual shopping. A major outcome of this three-year research programme was a national sizing survey in the UK. This survey used a fully automated process that captured 130 measurements, without body landmarks, from more than 11,000 people. These data have been used to create the first live database resource for the UK. This use of body scanning and measurement extraction software systems has created interest in other countries; 'Size USA' commenced in the summer of 2002.

This paper outlines the project aim, describes population changes since the 1951 Government-sponsored anthropometric study and indicates the way in which measurement sets were specified. Central to this project was the establishment of the first set of benchmark criteria on the basis of which to select the equipment with which the survey was to be undertaken; a description is given of the application of those criteria during the assessment of three-dimensional body scanners offered by manufacturers in several European, Asian and North American countries. The survey was organised into stages: recruitment; collection of data; data hosting; data analysis; software tools. The paper summarises the recruitment by project partners of subjects, the data collection process by universities across the UK, data analysis and work in progress to provide manufacturers and retailers with online access using software tools. Costs were shared by Government and industry partners. A preliminary account will be given of the emerging picture of the size of the UK population, which will emphasize the fact that this is the first time that it has been possible to establish not only the size but shape of the nation.

Keywords: clothing, sizing, anthropometric, body scanning, shape

1. The context for SizeUK

A national research project called the Centre for 3D Electronic Commerce was launched by the UK government in 1999. The project was designed to exploit commercial opportunities in the clothing industry afforded by 3D optical whole body scanners and the accurate data they capture.

The project was funded by the Government and a commercial consortium; initially a group of 20 companies, which later grew to include most leading clothing retailers in the UK. Since its inception more than 40 organisations have been involved in the Centre for 3D Electronic Commerce and the National Sizing Survey, either as full members, associates or contractors. They include higher education institutions engaged in clothing and computing research, and leading body scanner manufacturers.

Large Companies	**SMEs**	**Academic Institutions**
Arcadia Group plc	Bodymetrics Ltd.	De Montfort University
Bhs Ltd	British Standards Institution	Heriot-Watt University
British Airways plc	Caroline Ashby Design Ltd	Leeds College of Art & Design
Debenhams Retail plc	CSM3D International Ltd	Manchester Metropolitan Univ.
EBSCO/C&A	DataSize Ltd.	Nottingham Trent University
Freemans/Grattan Ltd	E-Centre UK	Southampton Institute
Great Universal Stores plc	Gieves & Hawkes	The London Institute
Hamamatsu Photonics UK Ltd	MOD Defence Clothing Agency	University College London
Hobson and Sons (London) Ltd.	Mark Winston Research	University of Central England
House of Fraser (Stores) Ltd	Royal National Institute for the Blind	University of Wales Institute
John Lewis Partnership	Select Research Ltd.	
Littlewoods Retail Limited	Smart Safety Gear Ltd.	
Monsoon Accessorize Ltd	[TC]2	
N Brown Group plc	TCT international plc	
NCR Financial Group Ltd	Wicks and Wilson Ltd.	
New Look Ltd.		
Oasis Stores plc		
Redcats (UK)		
Rohan Designs		
Speedo International Ltd		
Tesco Stores Ltd		
Videonetworks Limited		

The research project was designed with three constituent work packages:

- Virtual Shopping
- Custom Clothing
- the UK National Sizing Survey

Each was structured as a work plan that set out tasks, outcomes, a timetable and means by which it was to be managed.

1.1 Virtual Shopping

The Virtual Shopping project developed two and three-dimensional try-on clothing services for a variety of platforms: the World Wide Web, an in-store kiosk, interactive television and cellular phone. The Web platform and in-store kiosk prototypes were successfully trialed and the former has since been commercially developed and is now operating in the UK for a national home shopping company.

1.2 Custom Clothing

The aim of the Custom Clothing project was to trial a mass customisation service from 3D scanning to manufacture for the U.K. military, corporate clothing for traditional custom made clothing providers.

The military trial involved the provision of five formal dress uniforms for each of 200 naval officers.

A subsequent military project using a body scanner is now under way and interest is being shown in the service by UK police forces and the fire service.

2. National Sizing Survey

2.1 Rationale

As the focus of this paper is the third of the work packages, it is dealt with in greater detail. The UK National Sizing Survey was both urgent and important. There had not been a body sizing survey in the UK for half a century: during the intervening decades Britain had seen major demographic changes that would have tremendous implications for the clothing sizing systems used by industry, by retailers and by consumers. The earlier survey had been restricted to women, and it covered the population between the ages of 16 and 65 years. By 2001 it was necessary to extend the survey to reflect an age expectation beyond 80 years. Equally significant is the fact that Britain had ceased to be a monoculture, and that a survey would now have to reflect a very wide ethnic mix. A further consideration was that the lifestyles of the population have changed significantly.

The advent of reliable scanning systems provided an essential key to the success of this project, since the cost of a manual survey had now become prohibitive.

The key elements had been identified: the need for a survey; a partnership of government, industry and academe to tackle the task; and a technology that promised to solve the cost problem. The final challenge was to meet the requirements of the UK clothing retailers who would be part funding the survey and who would use the information that it would produce. Retailers entering the new millennium approached the National Sizing Survey with explicit concerns.

Customer focus. Shopping has increasingly become a recreational activity and enjoyment of the experience is paramount. A retailer that expects customers to take 10 garments into a changing room in the hope that perhaps two will fit will be thought to lack customer focus. Retailers sought to use the survey to gain a better understanding of their customers' shapes and sizes. Their intention was therefore to be able to identify and offer a garment fit that would suit specific customer profiles.

Returns. Clothing returned by customers as a result of unsatisfactory fit affects all retailers. Their objective was to reduce the number of returns, reduce lost sales and improve customer satisfaction.

Better Fit. Retailers recognised that a clear understanding of body shape and its relationship to size would enable them to cater more accurately for specific customer profiles. For example, a size '10' in the 36–45 age group would *not* be the same shape as a size '10' in the 18–25 age group. Hence it was not enough to aim to be accurate.

Marketing. An important requirement was that marketing data should be captured during the sizing survey. The objective was to get an understanding of factors influencing shopping behaviours – considerations such as fit, price, branding and so on. The marketing survey would of course reflect and explore the socio-economic composition of the UK today.

The SizeUK project was undertaken in two main phases: preparation, and implementation.

3. SizeUK: Preparation

Preparatory work was done during the period 1999-2001. The key tasks were:

- definition of a measurement set;
- implementation of a pilot study;
- benchmarking of scanning systems;
- development of a strategy for the recruitment of subjects to be measured.

3.1 Measurement sets for Women, Men and Children

The London College of Fashion worked with project partners to identify 50 body landmarks and 140 measurements. The departure point was an international standard (ISO 8559) – a standard that had been used by many scanner manufacturers to guide the development of measurement extraction software. This initial work incorporated requirements for traditional anthropometric measuring procedures, but those procedures (e.g. landmarks) were later modified to reflect the capability of the scanning system selected for this survey.

The final measurement sets included body landmarks and body locations for a range of vertical, horizontal and seated dimensions, including hand and foot measurements appropriate to the development of garment types for Women, Men and Children.

No.[1]	BODY DIM. / ISO 8559 / BSI 7231	BODY LANDMARKS	BODY LOCATION	WOMEN	MEN
01	Age		Age recorded in years	✓	✓
W1 M1 C1	Body weight (2.3.2) (BSI 01)	-	The value in kilograms indicated on a balance.	✓	✓
Vertical dimensions					
W2 M2	Height (2.2.1) (2.1.26)	High point of skull	Distance between crown of head and ground.	✓	✓
W3 M3	Chin Height	Lower point of front mandible	Distance between chin point and ground.	✓	✓
W4 M4 D	Head Height	High point of skull, lower point of front mandible	Distance between high point of crown of head and chin.	✓	✓
Hand and Foot Dimensions					
W141 M131 [W132] [M119]	Height of the Big Toe	Tip of the big toe	Distance between the highest level of the tip of the big toe on the right foot and the ground.	✓	✓

Figure 1: Extracts from SizeUK Body Measurement set

3.2 Pilot Studies

Three pilot studies were conducted: one each for Women, Men and Children. The sample of 200 subjects was representative of the Greater London population, as recorded for gender, age and ethnicity in the 1991 census. The trials enabled the team to assess:

- the Training Manual and sequencing, landmarking and measuring the body, recording and analysing data and recording the subject processing time;
- subject recruitment briefing, processing, reaction to scanning technology and completion of documentation;
- the organisation of the environment in which measurements were to be made – a changing room, manual and electronic measuring stations, anthropometric equipment, hygiene, the disposition of pilot study personnel;
- scheduling the process;
- practical problems in capturing the measurements specified – ease of scanning / re-scanning subjects.

On the basis of the pilot experience it was possible to revise documentation, assemble a body of data, compare results of manual and electronic measurement, test independent measurement shape analysis software and help to establish criteria for scanner benchmarking. It is noted that, although the preparation for a survey of children was completed, it was not implemented because the scanner technology was not sufficiently advanced.

[1] 'W' denotes Women; 'M' Men. Numbers in brackets refer to measurements listed DS1.1, Version 4.0. M numbers in brackets refer to measurements listed in DS1.2, Version 3. 'D' denotes a measurement that is derived from data, rather than being taken from body.

3.3 Benchmarking

The sizing survey took place as electronic body scanning equipment was beginning to achieve accuracy and reliability. There were two reasons for having high expectations of body scanning technology:

- firstly, the 3D body scanning automated process promised to capture a large volume of accurate data and make it possible to extract sufficiently rich information to meet the demands of the clothing industry;
- second, an automated process would be essential to make the cost of measuring a statistically significant sample of the UK population affordable.

Scanner benchmarking was undertaken in two stages. The first by questionnaire, where we sought to establish basic information on scanners and their current measurement extraction capability; the second the practical assessment of scanner systems by a small project team. The assessment was supported by major international scanner manufactures, and the team was able to visit installations in the USA, the UK, France and Germany.

Cyberware *(USA - WB4 and WBX)*
Hamamatsu Photonics UK *(UK)*
TC^2 *(USA - Textile Clothing Technology Centre)*
TecMath *(Germany - Vitus Pro and Vitus Smart)*
Telmat *(France)*
Wicks and Wilson Ltd *(UK)*

Figure 2: Scanner manufacturers visited during benchmarking phase

Central to the project was the establishment of a set of benchmarking criteria with which to evaluate the performance of systems and to select equipment to be used to conduct the survey. No such criteria appeared to exist; the SizeUK team therefore compiled three sets of criteria, based on previous experience during the project: The criteria related to:

(i.) scanner systems;
(ii.) subject characteristics;
(iii.) and measurement extraction.

Scanner Systems. The cost of each scanning system, its ease of operation, capacity for data storage, level of system support and whether or not the system could easily be transported to different sites.

Subject characteristics. The quality of scans - whether different underwear fabrics and colours, skin tone, height and weight of subject would interfere with scan capture. Consideration was given to body hair or the combination of hair, underwear and skin tones that might interfere with scan capture.

Also, most importantly, whether people would be happy to be measured in a scanner.

Measurement extraction. A static mannequin and a range of real people provided by each scanner manufacturer were used to test the measurement extraction process, which was carried out in two ways:

- by using the manufacturer's proprietary measurement extraction software, where available;
- by using independent software developed during the projects.

The benchmarking followed a defined sequence at each location, involving the repeated measurement of the mannequin and the selected human subjects recruited by the manufacturers.

At the time of our benchmarking survey considerable variations were found in the quality of 3D scanner:

- hardware (e.g. poor point cloud data, missing regions such as the inside of arms and legs and inconsistency between repeated measurements of the same person), and
- software (in some cases no software was available for automatic extraction, some systems required manual extraction or physical landmarks, some only allowed a limited number of measurements to be extracted, and in some cases there was a non-standard specification of landmarks and measurements).

Notwithstanding these contingencies, the project was able to select a scanner manufactured by TC^2. This company is a US Government-sponsored organisation that services US industry. The TC^2 scanner uses a set of white lights to project stripes over the body and has six cameras to capture the 3D shape.

The TC^2 system it was initially able to extract no more than 25 measurements but, by the time the development programme had been completed, all but 10 measurements could be extracted by automatic means. This study would not have been completed without the support of TC^2.

3.4 Recruitment Strategy

The initial target for SizeUK was 5,000 Men and 5,000 Women. However, a review of previous studies indicated that a lower figure could be used. The total number to be measured in the UK was the sum of the sample sizes in the subgroups. The measurement used to estimate the sample size was stature [1]. It was determined that stature would provide an appropriate estimate. (The estimate that would indicate the most subjects per cell and hence the smallest chance for error.) A review of within-age-group standard deviations, measured in other studies, indicated that 7 mm would be a reasonable within-cell standard deviation estimate for stature. The desired within-cell accuracy was set at 10 mm.

The calculation of within-cell sample size becomes:

$$\frac{|10| * \sqrt{n_i}}{7} \geq 1.96 \quad \text{or} \quad n_i = \left(\frac{1.96}{10} * 7\right)^2 = 188$$

This gave the minimum number of subjects required to give an accuracy of ±1cm at the 95% confidence level. The minimum number of subjects required to achieve 1 cm cell accuracy is 188. For SizeUK the primary recruitment criteria were gender (women, men), age (seven age groups 16-25, etc.) and region (three geographical regions containing eight data collection locations):

Figure 3: subject recruitment numbers

Secondary recruitment criteria included ethnicity (four groups), socio-economic (four groups) and perceived size (two groups).

The 1991 UK Census data were used to calculate the number of subjects required for each of the eight venues in the three regions into which the UK was to be divided for the purposes of the Survey.

4. SizeUK: Implementation

Clothing retailers, contractors and higher education institutions from across the UK came together to undertake the tasks and deliver outcomes according to specified time within management constraints set out in a further workplan.
The survey was organised into stages:

- Recruitment of Subjects;
- Data Collection;
- Data Hosting;
- Data Analysis;
- Software Tools.

4.1 Recruitment of Subjects

In order to raise awareness of the project and the need for volunteers, a press launch was held six weeks before the data collection commenced. Further press launches were held at each venue prior to data collection sessions. In addition, the project prepared literature and set up a recruitment web site.

SizeUK used a two-tier recruitment process: random sampling and quota sampling.

Random sampling. Retailers were responsible for the random sampling. Each was allocated a recruitment quota and each proceeded to target its own staff and customers, using mail shots, emailing and leaflet distribution, plus advertising and the web site. Each volunteer was asked to complete a short questionnaire, giving contact details, gender, age, ethic origin and perceived size.

Quota sampling. Subjects were selected from the returned questionnaire to meet national statistics related to gender, age, ethic origin, socio-economic group and geodemographics.

A contractor, Select Research Ltd., was retained to administer the recruitment of subjects. They were responsible for selecting subjects and inviting them to attend one of the eight data collection venues to be measured. A total of 25,000 people logged onto the web site. Each was promised vouchers to spend in partner stores if they were selected for measurement.

4.2 Data Collection

The United Kingdom was divided into three regions for the purposes of collecting data: the north, including Scotland; the midlands, including Wales; and the south of England. Eight higher education institutions established measuring centres in those regions. Key representatives from each higher education institution were invited to the London College of Fashion to receive training in manual and electronic data collection prior to data collection, which commenced in August 2001.

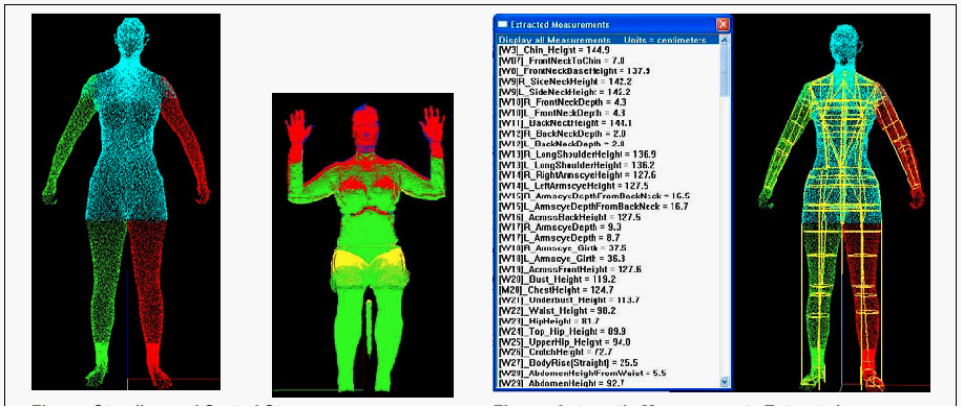


Figure 4: Standing and seated stance (left) and automatic measurement extraction (right)

At each of the measuring and scanning centres a venue was established in which subjects could be received and registered. Each subject was briefed and proceeded first to a changing room, then to the scanning station (where two scans were taken: one standing and one seated) and, finally, to a manual measuring station. The target for the team of seven processing subjects at most venues was 65; some days more than 100 subjects were scanned.

As discussed above, SizeUK identified 140 measurements. Of these approximately 130 were obtained by scanning each subject in two stances: standing and seated. That left 8-10 measurements to be taken manually; some relate to the difficulties that scanners have with hair, others to temporary limitations of the scanner size extraction software:

Manual Measurement	Women	Men	Commentary
Weight	✔	✔	Could be automatically uploaded to the PC
Height	✔	✔	Could be estimated from the point cloud data using SizeUK manual data. (Suitable for retail applications, but surveys may require accurate data.)
Head Girth	✔	✔	As above.
Head Arc	✔	✔	As above.
Over Bust	✔		Improvements in the software should eliminate this measurement.
Arm Hole Girth	✔	✔	As above.
Length of arm bent – centre back neck to elbow	✔	✔	May require change of Stance
Length of arm bent – centre back neck to wrist	✔	✔	May require change of Stance
Hand Girth	✔	✔	Improvements in the point cloud may eliminate this measurement.
Hand Length	✔	✔	As above.

Figure 5: SizeUK measurements taken manually

Subjects left the centres having completed a market research questionnaire and presented with a SizeUK bag containing a voucher, a printout of their scan and selected data and, in some cases, a dressing gown used during the scanning process. The last data were collected in February 2002.

Well over 11,000 subjects were measured. A total of some 1,540,000 measurements and 22,000 scans were collected. The data were augmented with information on shopping habits using a marketing questionnaire.

The tallest person measured was nearly seven feet tall, the shortest less than five feet. The youngest was 16 years and three days and the eldest a lady of 95 years, who was measured in the southern region.

4.3 Data Hosting

The data hosting of the UK anthropometric database is the responsibility of an Internet service provider.[2] Data that have been collected by SizeUK are stored on this secure web database and are now available for online analysis, using proprietary software tools. Each of the 11,000 subjects' sets of data comprises personal details (excluding name and address), two point clouds (one standing, the other seated), approximately 140 measurements (depending on gender) and data from the market research questionnaire. The data set for an individual occupies between 10 and 15 megabytes of storage. The analysed national data will also be held on this secure web database. The database will be available for five years (i.e. through 2007) for online private analysis by individual companies.

4.4 Data Analysis

A project team of contractors and academics[3] have completed an analysis of all four sets of national data.

Size Analysis: size range analysis, clustering the subjects; average size, mean and mode; percentiles - across specific groups; span of measurements within a size – min/max; confidence levels ±; relationship of measurements, e.g. shoulder to bust.

Market research: a similar analysis has been completed for market research.

Body measurement size charts. These have been compiled using actual and smoothed data. All height measurements have been correlated with subject stature, and girth measurements have been correlated with either chest or hip. The charts have been arranged to deal with sections of the human body (e.g. 'upper').

Shape analysis. This pioneering software has made it possible to visualise a wide range of modes within data sets and establish proportions between bust, waist and hips. This 3D scan information will also enable workroom stands to be developed.

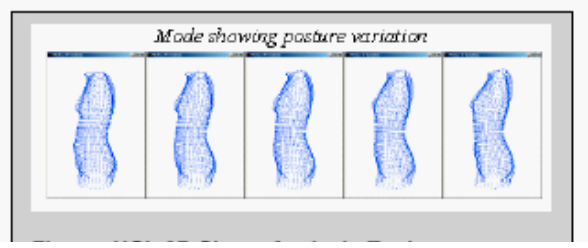


Figure 7: 3D shape analysis tool

[2] Bodymetrics Ltd., London.

[3] Shape Analysis Ltd., Mark Winslow Research, London College of Fashion and University College London.

In addition the team produced a wide range of correlations between all four sets of data that indicate how lifestyles relate to size, shape, clothing style and fit. All analysed data will be stored on the central database and will be accessed via a secure set of software tools.

4.5 Software Tools

A sophisticated suite of software tools for extracting and analysing information from 3D body size and marketing data has been developed by the SizeUK team.[4] The suite includes data processing software: for example, software for data integrity checking and the compilation of body measurement size charts.



Figure 8: The web-based software tools for 3D data analysis

Authorised access to all SizeUK data is via this suite of software tools that runs on the database server.

5. Conclusions

It would not have been possible to undertake this research and large-scale survey without three provisions.

- Advances in body scanning that had taken place over the three preceding years.
- The cost savings associated with the use of the most advanced information technology.
- The partnership of more than 30 interested parties, including Government, a significant proportion of the industry and a number of higher education institutions.

The aim of this project was to pioneer the use of 3D human body metrics in clothing sizing, manufacture and retail.

Retailers have an anthropometric database of the UK population with access to body size and shape. These can be used to update existing but out-of-date bodies of information that can readily be used to improve knowledge of the customer, target products more specifically and offer better fitting clothes.

[4] University College London.

A more significant challenge will be to pioneer creative and practical ways in which to exploit the new resource of information about shape.

6. Exploiting the new technology

6.1 UK Developments

In addition to project outcomes for UK partners, a contractual obligation associated with this Government funded project was the need to show general ways in which to exploit the commercial applications of the new technology in this field within the UK. It is hoped that the database will be made available for the myriad small and medium size enterprises, corporate clothing companies and other manufacturers in the UK clothing industry. A number of press and publicity events have already taken place. A press event is planned to launch the project outcomes and further presentations, publications, books, workshops and seminars are planned. New start-up companies – Bodymetrics Ltd., Shape Analysis Ltd. Data Size Ltd. have emerged during the project. Shape Analysis Ltd. and the London College of Fashion now offer a scanning bureau service based in central London.

6.2 INTERNATIONAL LINKS

The UK has thus established an acknowledged lead in 3D body scanning for the clothing industry, with its unique expertise in the conduct of the SizeUK survey. The methodology has become a blueprint for the national sizing survey and interest groups.

Outcomes from the study – the measurement specification and benchmarking procedures – have been used to assist with the development of European standards for anthropometric surveys in the eTCluster Group. Those European standards were recently presented at a meeting of the American Society for Testing and Materials in North Carolina, convened to consider the development of a related set of standards for the U.S.A.

SizeUSA has been launched by TC^2, drawing on experience gained through the SizeUK project. SizeMX is being planned by colleagues in Mexico and groups from Korea, South Africa and Europe have sought advice and guidance from members of the SizeUK team.

7. Further research

While SizeUK is now completing the project for which it was established, it has of course thrown up many new research questions, and further projects are beginning to take shape. The National Sizing Survey originally included a pilot study of children; but the 3D body scanning technology was not at that stage able to capture data from small moving targets! It is hoped that developments within the next year will make it possible to take that work forward, as well as developing links with existing and planned 3D CAD packages. Other research planned relates to made-to-measure clothing, further 3D body shape analysis and 3D colour visualisation.

References

[1] Daanen, H. “Civilian American and European Surface Anthropometry Resource (CEASAR).” Unpublished paper, TNO, Holland.