UK National Sizing Survey - SizeUK

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Abstract

During 2000-2001 a consortium comprising the UK Government, major UK Retailers and leading universities conducted what we believe was the first national sizing survey to use 3D body scanners with automatic and measurement extraction as the principal method of data collection. We conducted a systematic benchmark of 3D scanners and prepared a measurement set to use with 3D scanners for clothing applications. Following the survey we gave assistance to a number of other national surveys, including the United States, Korea and Thailand, and advice to France, Germany, Brazil and Malaysia. The aim of this paper is to provide a description of SizeUK to assist further countries interested in conducting a national sizing survey; it covers sample cell sizes, the organisation of recruitment, and data collection. We discuss strategies for exploiting the data produced, through data sales, creation of size charts and production of custom fit mannequins. We consider the lessons that have been learned that lead us to ask how we might do things differently today, using automatic registration and increasing the range of types of data collected in mobile scanner units. In conclusion, we look at the exploration of SizeUK shape data.

Keywords: 3D body scanning; sizing; survey; shape analysis; anthropometrics; clothing.

1. Introduction

In 2000 UK Government and leading UK clothing retailers funded a major research programme to pioneer the use of 3D body scanning technology in body sizing, custom clothing and virtual shopping. A major outcome was the national sizing survey: SizeUK [1]. The survey measured 5,500 women and 5,500 men to create a national anthropometric database, supplemented with an extensive lifestyle questionnaire for each subject.

This study was considered highly important as there had not been a national sizing survey in the UK since the 1950s and there had never been a survey of UK men. During the intervening years Britain, as with many industrial countries, had seen major demographic changes - age expectation was beyond 80 years, a broader ethnic mix, and sedentary lifestyles affected body shape, such as fast food and lack of exercise. These changes led to increasing complaints from customers about the fit of clothing and perceived commercial opportunities by the retailers [2].

The key to meeting these challenges was the advent of reliable 3D whole body scanning systems with accurate measurement extraction capability. The retailers were insistent that measurement extraction should be automatic, without having to place markers on the bodies of subjects.

In addition, branding and publicity in the national media were considered essential to encourage subject participation. To support the survey a SizeUK logo was created. Each retail partner produced advertising material for the data collection venues and was responsible for the visual presentation of a venue.

2. Survey planning

The preparation was undertaken during 2000 and comprised: a) creation of measurement sets suitable for the clothing industry, b) a proofing survey to verify the data collection process, c) benchmarking and selection of a scanner, and d) development of a subject recruitment strategy and infrastructure. We start by addressing the issue of funding a survey.

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2.1 Survey Funding

Survey funding comes in two forms: a) cash – to pay for the scanners and staff, and b) kind – donations of underwear, dressing gowns, survey premises, staff, shopping vouchers for participants etc.

The government and companies jointly fund most national sizing surveys (such as SizeUK), – the government providing cash contribution, typically 50% of the cost, and the companies providing a mixture of cash and kind. In-kind contributions are usually given a cash value that is offset against an individual company's total contribution. In return, the company gets the results of the survey 'for free' or at reduced cost.

2.2 Specification of Measurement Sets

Researchers at the London College of Fashion (LCF) worked with retail partners to identify 50 body landmarks and 140 measurements relevant to clothing product development. The departure point was the traditional anthropometric standard (ISO 8559) [3] – a standard used by scanner manufacturers to guide the early development of clothing measurement extraction software. The initial measurement specification (which incorporated requirements for traditional anthropometric measuring procedures) was tested during the proofing surveys and later modified to reflect the different measuring capabilities of scanning systems (e.g. shoulder angle, waist position). The final sets included body landmarks and body locations for vertical, horizontal and seated dimensions (including hand and foot measurements) required for the development of a wide range of garment types for Men and Women [4] These specifications were successfully implemented for the study.

2.3 Proofing Surveys

Two proofing surveys of approximately 70 men and 70 women were undertaken to verify all aspects of subject processing procedures. A team of researchers created a simulated data collection centre with a reception area, changing room, manual measuring station and two whole body scanners. Subjects were recruited according to national census data, (gender/age/ethnicity). Completion of consent forms, questionnaires etc. and other stages within the process was evaluated for duration, subject and team experience.

2.5 Scanner benchmarking

A comprehensive international benchmarking study of candidate 3D scanners was undertaken using a set of criteria to assess a variety of systems that were developed by a project team, led by Richard Allen (DLO DC RPS, Ministry of Defence, U.K.) [5].

Guideline requirements for satisfactory capture and extraction were:

- **Size** - a wide range of body sizes, e.g., for women US size 4 to 24, EU size 36 to 54, UK size 6 to 26.
- **Skin colour** - from very light to very dark skin pigmentation.
- **Head hair** - light colour to black; length short to long; loose or styled. A manufacturer was able to specify that some subjects must wear head caps, or that some subjects' heads must be measured manually.
- **Body hair** - from zero to thick body hair. Again, the manufacturer specified any necessary procedures in order to obtain accurate body surface measurements.
- **Perspiration** - scanner to deliver accurate body surface data in the presence of the levels of perspiration normally encountered.
- **Automatic Landmarking and Measurement Extraction** – as indicated earlier, SizeUK retailers required automatic land marking and extraction. There were three reasons: firstly they were against the intrusive process of placing markers on 'customers' bodies; second, that land marking was error prone; thirdly the time and cost involved of manual landmarking.

Benchmarking was undertaken in two phases.

- **Phase 1** – manufacturers were sent a questionnaire - seeking to establish basic information on scanners and their current measurement extraction capability.
- **Phase 2** - a SizeUK project team made an on-site, practical assessment of candidate scanner systems.

Phase 1 was conducted by the scanner manufacturers. First, to identify scanner information (size, scanning speed, hardware and software characteristics, subject pose, accuracy and cost etc.) and, second, to undertake two scanning tasks: one to record measurements taken from a mannequin (where each manufacturer scanned and manually measured a mannequin to extract six measurements); and second, to scan and manually measure a female subject, ideally with dark skin. The nine measurements that were gathered were based on ISO 8559. Scanner manufacturers were also asked to declare which of 132 desired SizeUK measurements the scanner could capture, both currently and with further short-term development (two months) along with the corresponding measurement accuracy (e.g. ±2 cm).

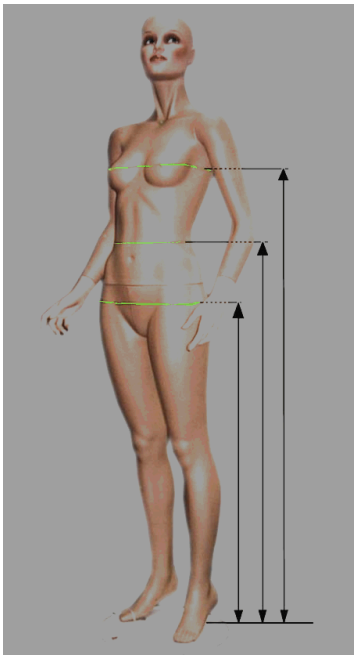

Figure 1: the mannequin used by SizeUK

Phase 2 was based on the results of the Phase 1 Assessment: a subset of systems was proposed for the next round of tests. A small team from SizeUK visited installations in the USA, the UK, France and Germany - Cyberware WB4 and WBX [6]; Hamamatsu Photonics UK [7); TC[2] Textile/Clothing Technology Center [8]; Human Solutions Vitus Pro, Vitus Smart and Pedus foot scanner [9]; Telmat [10); Wicks and Wilson Limited [11] and Shoemaster (a foot scanner company) [12].

Phase 2 methodologies and analysis of the systems was divided into:

Visual appraisal of data quality: designed to ensure that each image had minimal data loss due to subject movements and measurement volume. Fabric Samples were used to assess scanner performance against various coloured, contrast or surface finished fabrics.

On-site questions and observations: each manufacturer demonstrated their systems' capabilities with regards to size and shape software. There were significant variations between levels of automation, price, rental agreements etc.

Measurement extraction from scans of mannequin and living subjects: (Figure 1.) The main criteria for choosing a scanner for the SizeUK survey were measurement repeatability and number of measurements that were the same as the manual measurements taken during the benchmarking to a statistically significant extent. Three sets were extracted:

- manual measurement from scans, using interactive tools
- automated measurement using proprietary software
- automated measurement using standard software (Hamamatsu).

Table 1: allowable error from US army survey

Upper arm girth	0.8	Ankle girth	0.4
Forearm girth	0.5	Height	1.1
Chest girth	1.5	Bust height	1.1
Under bust girth	1.6	Waist height	0.7
Waist girth	1.1	Crotch height	1.0
Hip girth	1.2	Knee height	0.6
Waist to hip	0.6	Calf height	0.3
Top hip girth	1.2	Neck column girth	0.6
Thigh girth	0.6	Elbow girth	0.4
Knee girth	0.4	Wrist girth	0.5
Calf girth	0.5	Centre shoulder body loop	2.2
Mid thigh girth	0.4		

The test used was the t-test. However, some of the scanning systems were so variable on their measurement extraction that limits had to be applied to the measurement variation. These values were taken from a U.S. survey undertaken in 1988 [12].

Where the Allowed Error was matched in the U.S. Army Survey these amounts were used and, where no matched measurement existed, then 1.0 cm was assumed.

The significance of using Allowable Errors was that a scanner with very large variations between scans could, 'statistically,' perform very well. If, however, applied limits of variation are set, then these

scanning systems would be eliminated and only systems displaying a high degree of reproducibility would reach the benchmark standard.

During the scanner evaluation process it was found that several systems exhibited large variations in results between scans. This could be due to several reasons: a) errors in the raw scan data (e.g. presence of outliers or holes), b) poor landmark detection, c) poor scan capture, and d) poor or simple segmentation of body parts.

Some scanning systems showed extremely variable results, which displayed no trend or offset that could be determined. However, two of the systems displayed repeatability levels greater than manual measurement and judged as suitable for SizeUK. In the final analysis, the fact that the TC[2] software was able to automatically landmark and to extract all but nine of the required measurements was key to the selection of that system. The TC[2] system uses a set of white lights to project stripes over the body and has six cameras to capture the 3D shape.

2.5 Recruitment Strategy

The initial target for SizeUK was 5,000 Men and 5,000 Women. 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. [13.] 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. [14.] The desired within-cell accuracy was set at 10 mm. (Figure 2.)

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

Figure 2: calculation of within-cell sample size

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 (10 yr bands 16-25, etc.) and region (Table 2).

Table 2: subject recruitment numbers

Age Group	16-25	26-35	36-45	46-55	56-65	66-75	76+	SUM
Region 1	188	188	188	188	188	188	188	1316
Region 2	188	188	188	188	188	188	188	1316
Region 3	188	188	188	188	188	188	188	1316
Totals	564	564	564	564	564	564	564	**3948**

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 three regions into which the UK was to be divided for the purposes of the National Sizing Survey.

3. Data collection

This section covers subject recruitment, subject processing and data hosting

3.1 Subject Recruitment

Subjects were recruited through a major press campaign and by the retailers who used mail shots, email and leaflet distribution to target their own staff and customers.

In order to raise awareness of the project and the need for volunteers a national press launch was held in July 2001, six weeks before data collection commenced. Further press events were held at each venue prior to data collection. As an incentive for participation in the survey, subjects were offered a £20 (23€, $30) shopping voucher, which the retailers considered 'cost neutral'.

Subjects could register their interest in participating in the survey via a call centre, web site or submitting a paper-based short questionnaire. A contractor was retained to administer the recruitment of subjects, select subjects from the pool and to brief them before inviting them to be scanned at one of the data collection venues. A total of 25,000 people logged onto the web site.

3.2 Subject processing

Data were collected by eight contracted universities (Edinburgh, Heriot-Watt University; Leeds, Leeds College of Art & Design; Manchester, Manchester Metropolitan University; Nottingham, Nottingham Trent University; Birmingham, University of Central England; Cardiff, University of Wales Institute; London, London College of Fashion; Southampton, Southampton Institute) located in city centres, and one shopping mall, each serving as a measuring venue in one of the three regions – North, Midlands and South (Figure 4).

Figure 4: data collection regions in the U.K

Key personnel from each university were trained by the LCF in running a venue and in manual/electronic data collection.

The scanning operation required that each venue have a trained team of seven people, and a target was set to process 65 subjects each day although more than 100 subjects were scanned during many sessions.

On arrival subjects were registered, signed a consent form and completed a marketing/lifestyle questionnaire, before being measured. At the request of the clothing retail partners all subjects wore their own classic underwear (without trimming, under-wires, support materials) unless their garments were ill fitting, in which case alternative underwear was provided. They were scanned in a standing and a seated pose. 130 measurements were extracted in a matter of seconds by the software [Fig 5]. These were supplemented by ten manual measurements (weight, height, head girth, head arc, chest over bust, arm scye, length of arm bent to elbow and wrist, hand length and width). Of these ten, some related to difficulties that scanners have with hair, others to occlusion and temporary limitations of the scanner in land marking and measurement extraction software.

Scan data and hand measurements were recorded on CDs and merged with questionnaire data prior to loading onto a database. Well over 11,000 subjects were measured. A total 22,000 scans were collected, yielding some 1.5 million measurements. The data were augmented with information from the marketing questionnaires.

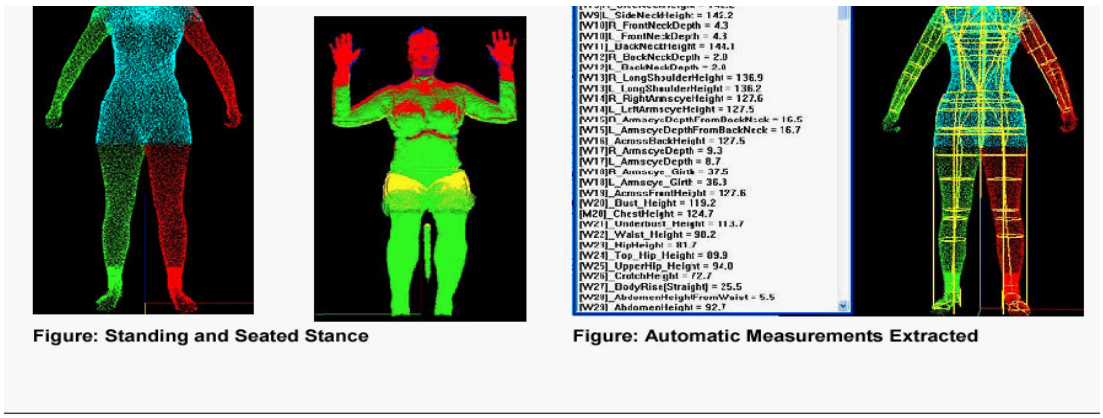

Figure 5: Standing and seated stance (left) and automated extraction (right)

3.3 Data Hosting

Data collected by SizeUK are stored on a secure web database. Each of the 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.

4. Data analysis

To reiterate, extensive research was undertaken both to protect the data with regard to the EU's data protection laws and to protect the commercial value of the data (estimated at £3m). Retailers were offered three options to access analysed data - using on-line tools, commissioning a custom set of data or using standard analysed data.

4.1 Online Software Tools

A suite of software tools, developed by UCL computer science team, run on the database server and can be used to check data integrity, extract and analyze 3D body size and marketing data, and compile body measurement size charts for selected markets.

Figure 6: the web-based software tools for 3D data analysis

4.2 Custom analysis

In the case of a retailer who did not have in-house skills to use software tools and analyze data online, a custom analysis service was provided. Data can be processed for a particular region, age group, gender or set of measurements.

4.3 Analyzed data

In addition to online and commissioned analysis, a group of expert contractors (Shape Analysis Ltd., Mark Winstone Research, Somavision Ltd.). and academics (London College of Fashion and University College London) produced a standard set of analyzed national data for each of the data sets.

Measurement data comprised size range analysis, clustering of subjects, average size, mean and mode; percentiles - across specific groups; span of measurements within a size. 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. Results indicated that, during the last 50 years, the UK population had grown taller, larger and heavier. The heaviest women were aged between 45 and 54 years, while the heaviest men were in the 55 – 64 age group. The tallest men were found in the 20 - 24 age group and, for women, within the 25 - 34 age span.

Market research data had a similar set of analysed data as those produced for measurements.

Body measurement size charts were compiled using actual and smoothed data. Height measurements were correlated with stature and girth measurements with either chest or hip. The charts were arranged to deal with sections of the human body (e.g. 'upper' body).

Shape analysis was conducted using pioneering software that made it possible to visualize a wide range of modes within shape data sets and establish proportions between bust, waist and hips. (Figure 7.) [15.]

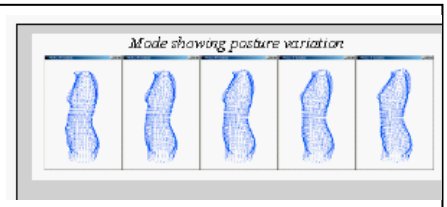

Figure 7: 3D Shape Analysis Tools

These analysed data sets were supplemented with a range of correlations between all four data sets indicating how lifestyles relate to size, shape, clothing style and fit. All analyzed data were stored on the central database.

5. Data exploitation

A national sizing survey such as SizeUK produces a wealth of data: body and lifestyle, linear measurements, 3D shape, point clouds, market research, all highly valuable to a range of sectors including clothing, healthcare and sport.

Making these data available for exploitation is surprisingly complicated and raises a number of issues:

- **Funding** - whether the survey was funded by government or industry, and hence whether data will fall into the public or private domains;
- **Intellectual property rights** (IPR) –legal ownership of the data;
- **Restricted access** – whether the survey partners wish to restrict access for commercial advantage, or whether data protection laws consider point clouds personal data and hence subject to national data protection laws;
- **Data sales** – whether the data needs to be sold, to (for example) recoup any budget deficit;

Figure 8: SizeUK Custom Fit

- **Target market** – whether clothing companies are principally interested in measurements, or healthcare, which has major implications for the design of surveys;
- **Technical requirements of customers** – whether customers prefer access to raw data or to processed data in the form of size charts and custom fit mannequins.

The UK Ministry of Industry (DTI) and the major UK retailers, as stated above, jointly funded SizeUK, with the DTI allowing the UK retailers to jointly own the IPR. To protect the raw and analysed data, the results are held on a secure database and are accessible via software tools. Extensive investigations were undertaken to see if the raw data could be made available on magnetic media, such as CD-ROM, and the conclusion drawn was that these methods were insecure and tantamount to making the raw data public domain and hence valueless to the partners.

The results of SizeUK were therefore made available in the following forms.

- Analysed data are available on a password-protected CD ROM to the UK retail partners
- A suite of online software tools permits SizeUK partners and purchasers of the data access to the database.

- SizeUK clothing fit mannequins have been created for generic UK female and male body shapes and sizes with the retail partners by Sizemic [16]. No other mannequin company has access to the SizeUK data.
- SizeUK morphological block and graded patterns developed in conjunction with TPC [17].
- A bureau service is also provided for bespoke data analysis for specified market segments e.g. Size charts, fit mannequins, graded patterns and in some cases, correspondence of fit model shape to a specified market shape.

6. Lessons learnt

In this section we comment on 'lessons learned' from SizeUK. Most things worked well, but some issues are worth highlighting.

Survey Planning

In planning three issues are notable: funding, scanner selection and recruitment strategy. With regard to funding, most surveys (SizeUK, SizeUSA, SizeFrance, SizeThailand, etc.) used a mix of government and industry support, comprising 'cash' from the government and 'cash' & 'kind' from the industry partners. However, while this encourages industrial participation, it is important to obtain prior agreement with partners on common in-kind contributions (e.g. personnel cost) and to allow for the popularity of some retailer vouchers.

SizeUK conducted a comprehensive scanner benchmarking exercise and, although there are now several ISO compliance standards setting out protocols to ensure compatibility of measurements as described in ISO 7250-1 (revised in 2008) [18]; methodologies for compatible anthropometric databases ISO 20685 (2005 & revised in 2010) [19], [20] and requirements for establishing databases ISO 15535 (2006) [21]; we would still recommend that survey teams undertake a benchmarking exercise. In particular (as in the case of SizeUK), if additional body measurements are required for either product or discipline-specific applications, or as new, upgraded or cheaper systems become available.

The recruitment strategy was based on a previous study to ascertain sample size from 'stature' for each 10 year age group, selected to match existing clothing market segments. ISO 15535 now recommends age group divisions and methods for estimating the number of subjects required in a sample. An example explaining how, by measuring 443 subjects, an investigator can ensure desired levels of relative accuracy and confidence are achieved for three variables is reproduced below in Table 3. [21].

Table 3: Minimum sample size for 95% confidence and 1% relative accuracy

Stature	$N = \left(1{,}96 \times \frac{3{,}8}{1}\right)^2 \times (1{,}534)^2 = 130{,}5 = 131$ subjects
Chest circumference	$N = \left(1{,}96 \times \frac{7{,}0}{1}\right)^2 \times (1{,}534)^2 = 443{,}0 = 443$ subjects
Shoulder (bideltoid) breadth	$N = \left(1{,}96 \times \frac{5{,}3}{1}\right)^2 \times (1{,}534)^2 = 253{,}9 = 254$ subjects

Another extremely important recruitment issue (ignored by some surveys) is ensuring that the subjects selected are in fact a representative sample of the population with regard to age, gender, ethnicity and socio-economic characteristics. In addition, obtaining a sample that is representative of the spread of sizes within a population is particularly important as recruitment in a specific

venue/location may exclude certain sized groups. Census data were used to confirm population mix and previous industry surveys to ensure anthropometric representation.

6.2 Data Collection

One of the biggest problems encountered by was the marrying together of a subject's registration data, body scan, manual measurements and lifestyle questionnaire. In the subsequent SizeUSA survey, a unique barcode for each subject was used and worked well, and this has subsequently been adopted by other surveys.

A further issue was that, although we collected two scan poses, one standing the other seated, and created a specification of landmarks and measurement relevant to clothing requirements for the standing and seated pose, there where no resources available to develop automatic measurement extraction software for seated scans. This capability is now available, and - although it was initially created for military applications, is available for £20.000 (€23,500, $30.000.00). Further developments include automatic breast extraction software, which has been found useful for both clothing and health applications.

6.3 Data Analysis

We undertook extensive basic data analysis on behalf of the survey partners, and, while this produced a mass of statistical data in formats requested, retailers really required ready-to-use size charts, standard block patterns and mannequins or customized versions to match their selected market.

6.4 Data Exploitation

Most national surveys have typically sold their data but each has addressed data exploitation differently. SizeUK estimated the value of the data collected as €3m, and each company's contribution as £40,000-£80,000 ($59,000-$118,000, €46,000-€93,000), depending on turnover. This complicated the sale of data especially to small retailers or individual designers at a price they could afford.

7. Automating a national sizing survey

With regard to the future, SizeUK was undertaken as a 'one-off' survey to meet the urgent requirements of the UK clothing industry. Since that time interest in conducting national anthropometrics surveys, and on a regular basis, has mushroomed.

The drivers are:

- **Markets** - to support clothing, healthcare and sport.
- **Subject groups** - to scan different groups: children, pregnant women, older people, disabled, obese etc.
- **Sample size** - To collect data on small cohorts (e.g. 20-30 people) and in a large number of locations.
- **Data** – there is now a demand for supplementary information including foot scanning, biomechanics, body composition and physiological function.
- **Cost** - to reduce the cost, speed and complexity of data collection.

This has led to automating the survey via a registration web site, mobile data collection unit and automated analysis tools.

Figure 9: Mobile Data Collection Unit

We have developed a generic web site that can be readily cloned. It comprises a registration questionnaire, description of the data collection process etc. and produces a personal barcode for the subject.

We have also commissioned a mobile data collection unit (see Figure 9) that contains a 3D scanner, electronic height gauge, body composition monitor, Telmedcare, and an electronic tape measure, The mobile unit has full internet capability, can be powered from the mains or by a generator, and can be moved by any 4 x 4 vehicle. It has been used for a number of surveys, including a Child Growth Foundation event [22] and a New Dynamics of Ageing project [23].

Work is continuing to produce suites of data analysis tools for different sectors such as clothing, sport and healthcare.

The model is essentially the same; a subject's record is extracted from a secure server into the data collection unit, is populated with data from 3D scanners and other equipment, and then copied back to the server. Then a professional can use the analysis tools to access the record and apply appropriate analytics to the data, or even allow the subject to have access to their personal anthropometric and other data. This is especially interesting for diet and exercise in the healthcare area.

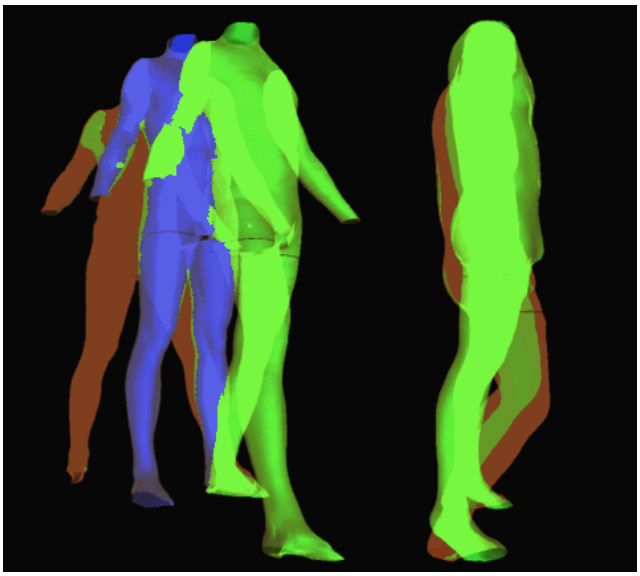

Figure 10: Animating body scans using captured pose variation

8. Conclusions

The great thing about 3D body scanning is the potential it has for various sectors: clothing, healthcare and even sport, and - although we refer to SizeUK, SizeUSA and Size Germany –scanners are in fact shape capture devices, and much future research will be in shape analysis.

A significant outcome has therefore been the use of *shape* analysis tools to exploit 3D capture. Nevertheless, while we now have the ability to visualise and identify 3D shape, (for clothing applications, for assessing obesity [24] and for animating body scans [25]), there remains a predominant interest in *linear* measurement applications.

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