E-TAILOR: Integration of 3D Scanners, CAD and Virtual-Try-on Technologies for Online Retailing of Made-to-Measure Garments

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10.E-TAILOR: Integration of 3D Scanners, CAD and Virtual-Try-on Technologies for Online Retailing of Made-to-Measure Garments

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Abstract

A number of initiatives have arisen recently in many European countries evolving around the concepts of made-to-measure garment manufacturing and the new generation of online apparel shopping. The combination of these new services has been made now possible by the emergence of technologies such as 3D whole-body scanners, 3D CAD systems for the customisation of existing styles, virtual-try-on visualisation techniques and the new generation of smartcards. E-TAILOR[4] aims to establish an innovative paradigm for virtual retailing services of customised clothing that tackles related problems (different sizing systems, fitting problem, high cost, data privacy and lack of interfaces). The developments in E-TAILOR can be grouped together in terms of the following infrastructures:

1. A *European sizing information infrastructure* (ESII) which will contribute to the solution of the sizing inconsistencies problem in general.
2. An advanced *Customised Clothing Infrastructure*, enabling the ordering and production of custom-made garments at reasonable prices, in a short time and with a close-to-perfect fit.
3. An innovative *Virtual shopping infrastructure*, enabling customers to visualise themselves wearing garments on offer at e-kiosks installed in traditional stores, as well as online (in internet shops).

Introduction

Customisation: A New Challenge for the European Clothing Industry

The term "customization" implies a wide range of personalised services, ranging from a simple choice of fabric colour, fabric type, accessories, etc. to mass customisation (e.g. fitting sizes to a large group of customers) and to made-to-measure (MTM), e.g. garments tailor-made to fit a specific customer's body shape and preferences. Solutions developed in the E-TAILOR project will tackle all the above problems.

In the year 2000, the European textile and clothing industry generated a total turnover of almost € 200 billion, employing some 2.2 million persons in about 114,000 firms. This industry accounts for 7.6% of all industrial employment and 4.2% of the added value. Out of these totals, the clothing and knitting industry, which will be directly affected by the technologies developed in E-TAILOR,

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[1] G.A. Kartsounis is acting as Scientific Coordinator of the E-TAILOR project, under a contract between AUA and Athens Technology Centre SA.

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accounts for about 50% of the turnover (€ 100 Bio), 68% of the employment (1.5 million) and 70% of the number of companies (80,000). Clothing products representing a total value of € 165 billion are sold every year in the EU market [1].

The EU clothing and textile industries are characterised by very intense international competition. EU producers face fierce competition from the exports of new industrialised countries (NICs), whose low wage costs and low social charges give them a considerable competitive advantage. Labour costs probably represent the most important cost factor in the manufacture of clothing, where labour remains the determining element in the production process.

The European clothing industry is therefore handicapped at present in the field of low-cost mass-produced clothing. It needs to seek the development of new market opportunities, based on customisation, combined with the traditional creativity of European designers and the creation of vertical networks of retailers and manufacturers. This is one of the alternatives, based on the exploitation of the competitive advantage of proximity, which is critical for the cost-effectiveness and success of customised services (delivery costs and delivery times).

Online Apparel: Obstacles to Selling Clothes Online

A number of distinctive aspects of the fashion industries provide challenges to the implementation of business-to-consumer (B2C) electronic commerce.

The most important is the difficulty of accurately characterising the product online. Many of the characteristics of a garment that are decisive in the consumer decision-making process (predominantly fit) are difficult to communicate virtually. Selecting the right size is not a straightforward decision, since different manufacturers use different size charts for different types of garments. Size recommendation is a problem of relating body measurements to individual garment sizes.

While the volume of online apparel sales is significant (though mainly in the United States), it still represents a small percentage of all apparel sold, and significantly lags behind Internet penetration in other consumer goods markets (e.g. books and music). Internet shopping for clothing products is increasing rapidly in Europe. However, it still represents a minor percentage of total apparel sales through traditional channels.

Overview: The E-TAILOR Suite of Products

Figure 10.1 illustrates diagrammatically the main functional components of E-TAILOR infrastructures. The E-TAILOR products can be grouped into three main categories, according to their placement across the value-added chain.

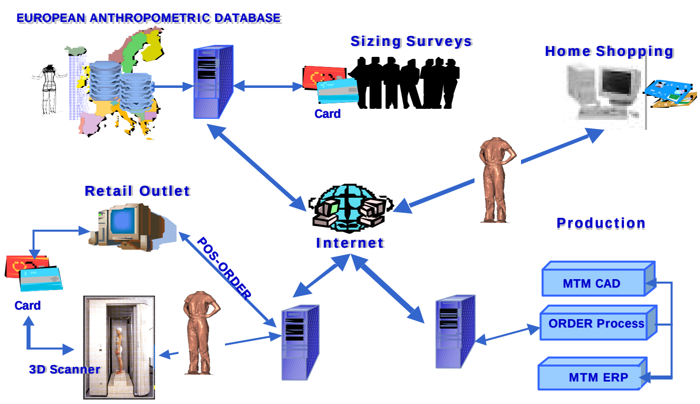


Fig. 10.1. The functional components of the E-TAILOR infrastructures

The term "infrastructure" is used to indicate the holistic nature of the products and standard interfaces, which are designed to meet the critical needs of:

- the production chain (Customised clothing infrastructure, CCI)
- the retail, e-commerce chain (Virtual shopping infrastructure,VSI)
- the entire clothing and retail industry of mass-produced, mass-customised or made-to-measure products, as well as other related industries relying on up-to-date anthropometric data (European sizing information infrastructure, ESII).

Table 10.1 summarises the E-TAILOR suite of products, grouped according to the above classification.

Table 10.1. List of E-TAILOR products and related standards

INFRASTRUCTURE	PRODUCT	STANDARD / INTERFACE
European Sizing Information Infrastructure – ESII	Web-enabled European Anthropometric Database (EAD)	Standard 3D body and measurement representations
	Advanced shape analysis S/W	
	System independent body measurement S/W	
Customised clothing infrastructure – CCI	E-TAILOR business-economic Simulator	CAD interoperability standard
	Intelligent pattern alteration S/W	
	Morphological editor S/W	
	Customised order clustering S/W	
	Web-enabled components for MTM integration	
	Test bed for SMEs (SME oriented integration platform)	All E-TAILOR standards
Virtual Shopping Infrastructure – VSI	Virtual-try-on S/W	Virtual-try-on S/W interfaces
	E-TAILOR smartcard applications	Java, XML, OCF
	Virtual shop (integration platform)	

S/W=software; SME=Small-to-medium-enterprise

The development of key innovative products in parallel with the development of standards (in co-operation with other EU and national projects and initiatives) is probably the most innovative aspect of the project and is the cornerstone for the successful exploitation of the E-TAILOR suite of products.

Main Innovative Aspects

System-Independent Measurement Software

The system-independent measurement software forms a basis for deriving body measurements from 3D body scans recorded by possibly different pieces of hardware. Thus, it provides a link between the scanner hardware and the whole E-TAILOR MTM process chain.

Requirements

The main requirements which have to be met by the system-independent measurement software in the MTM chain are applicability to 3D body scans independent of the manufacturer of the scanning system, automatic extraction of all measurements needed for the made-to-measure process, measurements taken according to standardised measurement rules and configurability to individual customers' needs.

Approaches to Automatic Body measurement

Methods for the automatic acquisition of measurement data from 3D scans of human beings can be distinguished by the amount of knowledge about the structure of the human body which are inherently contained in the respective algorithms. Basically, three categories of approaches can be identified on the basis of this criterion.

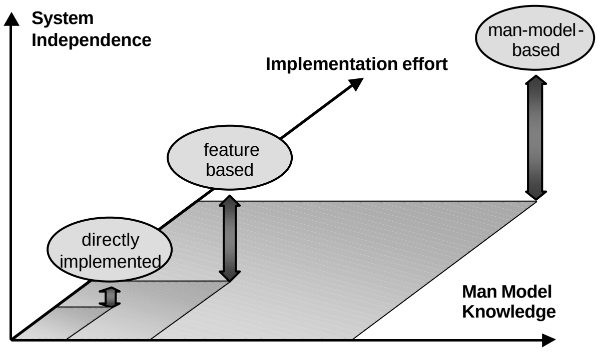


Fig. 10.2. Comparison of automatic body measurement methods

Figure 10.2 illustrates the different amounts of explicitly represented man-model knowledge which are needed as premises for each of these methods.

Directly implemented measurement algorithms. The measurement algorithms are implemented directly for each specific measurement (i.e. there is a set of generally independent measurement algorithms). There is usually no hierarchical approach for taking some measurements on the basis of others. As a result, the algorithms are usually strongly dependent on the input (posture of the subject, texture/attached landmarks, scan properties such as resolution, structure and closeness, etc.), i.e. highly dependent on the scanner manufacturer.

Feature-Based Measurement. Feature-based measurement methods follow a two-step-approach. In the first step, a set of predefined features (body landmarks such as the acromia, the top of the head, or the location of the wrist bone) are detected on the scan. In the second step, measurements are taken, usually by applying a set of parameterised measurement tools (virtual "tape measures", such as circumferences or lengths, parameterised, by angle, displacement, etc.) to the pre-detected features on the scan by use of implicitly or explicitly defined measurement rules. The application of measurement rules may lead to new features, on which additional measures are based, i.e. there usually exists a measurement hierarchy.

The principle is illustrated in Fig. 10.3. Feature points are detected by using structural knowledge of the human body and analysing topological properties in certain body regions. Measurement rules are defined on the basis of the extracted body features. For instance, chest girth could be defined as the circumference of the body surface on a horizontal intersection plane through the nipples.

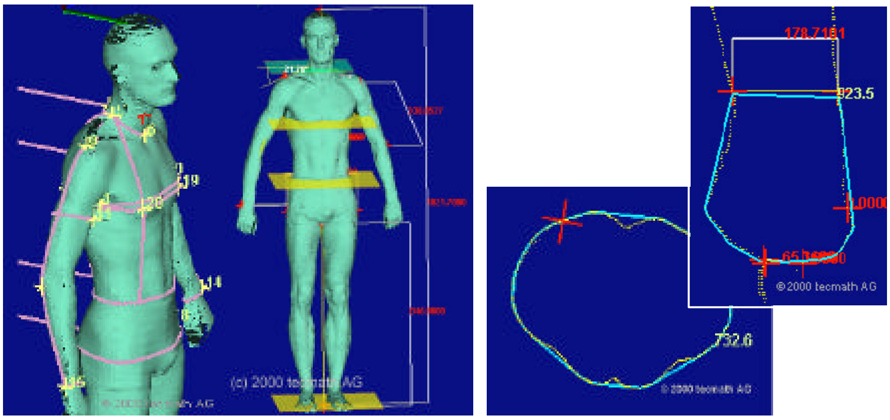


Fig. 10.3 . Feature-based body measurement

Man-model-based measurement. Man-model-based body measurement methods rely on the use of a fully articulated, functional man model as an interpretation context for the scan data. CAD man models are typically constructed on the basis of a skeleton (the internal kinematic structure) and an outer surface model representing the skin. For the purpose of interpretation of body scans and measurement extraction, the man model is used as an explicitly represented reference structure carrying anthropometrical and anatomical knowledge about the human body. The body dimensions, internal structure, posture and “skin” of the man model are adapted such that the outer surface of the model matches the scan as exactly as possible. Measurements can then be extracted by the intrinsic measurement retrieval methods of the man model (i.e. the man model can directly provide its measurements, which as a result of an adaptation process, reproduce the scanned body’s measurements).

Method Applied

While directly implemented measurement techniques offer the advantage of minimum implementation effort for a specific type of scan and set of measurements, they suffer from the significant drawback that each adaptation (for a different type of scan or a modification of the measurement method) often means high (re-)implementation effort. Thus, they lack flexibility and are hardly generic. Man model-based measurement methods are extremely flexible and generic (even, to a certain degree, posture-independent from the fact that the man model adapts to the posture of the scanned person). However, they require the availability of a fully functional man model (which is in itself computationally very complex and whose creation presupposes considerable anatomical knowledge and has extremely high implementation costs).

With respect to system independence, implementation effort and the required man model knowledge, feature-based measurement techniques provided the most appropriate approach for designing system-independent body measurement software within the framework of the project described here.

Virtual Try-on

Virtual Try-on offers online customers the possibility to see themselves or a model matching their body measurements and shape (a configurable generic model) wearing simulated garments. Existing systems currently offer static simulations of dressed generic models.

Research in E-TAILOR is focusing on the following two major directions:

- Online animation (e.g. catwalks) of dressed bodies enabling online visualisation of the dynamic interaction of simulated garments on moving bodies
- Accurate garment simulation on "real" (scanned) customer bodies

Creating Virtual Bodies and Clothes for the Online Web Application

The method adopted for both body representation and animation for online web applications is to use generic models. We can define one or several generic models [2], to be adapted to each personal shape and skin texture. The main advantage of using generic models is that one can give necessary information in a pre-processing stage and then online calculation can be performed quickly. This also provides animation information automatically. Our basic new idea is *to consider an avatar or virtual model as a database of a combined set of data, including the 3D shape and the structure of how to animate it*. The human modelling approach starts from default virtual human generic models, including shape and animation structures, and the generic shape is transformed into a new virtual model according to the scanned body information (Fig. 10.4).

For the generic body animation, we apply a walking motion obtained from a VICON TM motion capture system. Six cameras with a sample rate of 120 Hz are used along with 25 mm markers.

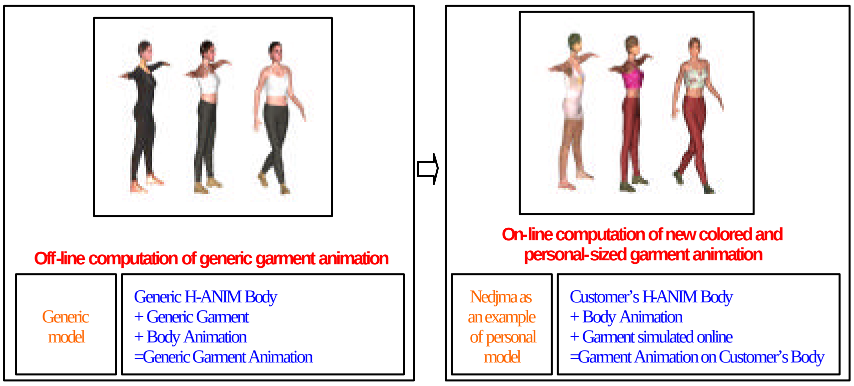


Fig. 10.4. From generic to personalised body and garment simulation and animation

As described in [3], we use a similar approach for garment reconstruction and animation on a moving body surface. The garment is made from 2D patterns of garment surfaces. The approach to garment simulation takes its inspiration from the traditional garment industry, where garments are created from 2D patterns and then seamed together. A 3D garment simulator includes the mechanical model, a collision engine, rendering and animation. The patterns then need to be discretised into a triangular mesh. Once the patterns have been placed around the body, a mechanical simulation is invoked to make the patterns come together along the seam lines. Consequently, the patterns are attached and seamed, obtaining a shape influenced by the body shape. The mechanical simulation results in an animation of the garment on the body, accounting for the collision response and friction with the body surface. The final visual look of the garment is displayed through its material properties, i.e. colours, shininess and texture, which are some of the rendering parameters. Geometrical complexity is another very important consideration, as the rendering time, as well as the computation time for the animation is directly proportional to the number of polygons to be displayed.

We have performed calculations of a generic garment fitting a generic body and have built a database according to the style such as trousers, skirts, pullovers and one-piece dresses.

The garment animation is calculated on a moving generic body with given skeleton animation sequences. For each time frame, we save the garment surface information, which is used in the online calculation of a made-to-measure garment simulation.

The most important idea in our approach is to use a pre-calculated generic database for bodies and garments and adapt it to the personal data (measurement data from scanned bodies). For the Web application, fast calculation is a critical issue. Our method requires as much pre-calculation as possible for the generic database so that we can then minimise the calculation that is done to personalise the given generic data.

Body Creation Based on Measurements from Scanned Data. Key measurement data from a scanned body is used to create a new, personalised virtual model. The system is composed of several modules working in a pipeline (Fig. 10.5 gives an overview of the pipeline). Our generic body model is composed of a skin mesh and a skeleton. The skeleton hierarchy that we have chosen to use is the H-Anim level of articulation (LoA) 2 hierarchy [4].

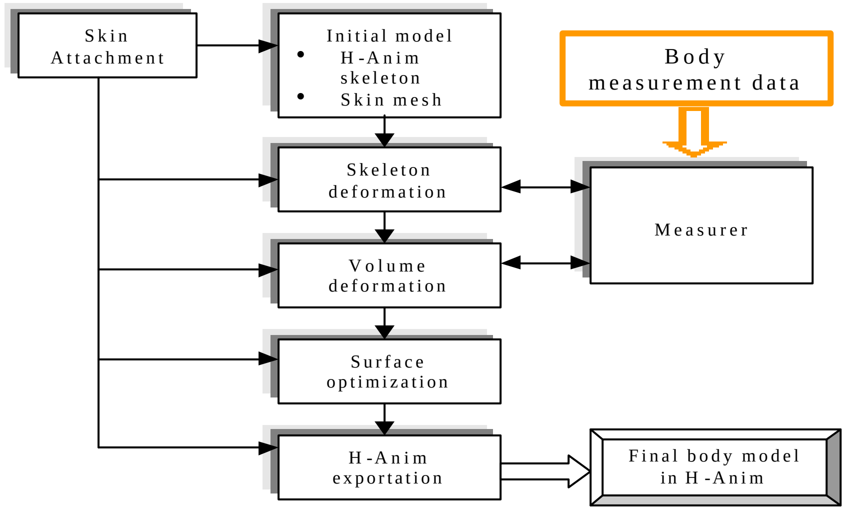


Fig. 10.5. Overview of the pipeline for generic body adaptation to customer's individual measurements

Fitting Generic Garment Animation to Personally Sized Bodies. Given a body created from a generic model, the system modifies the animation of the generic garment. As described in the previous section, the program generates bodies from a generic model using the measurement data from the scanned body. The same kind of methodology is applied to garments. A set of generic garments is attached to each generic body. The generic garment animation sequence is then automatically adapted to the personally sized body.

In each frame of the garment animation, the vertex position of the garment is adapted to the skin surface of the personally sized body. The method consists of applying a local scale factor to garment vertices. This local scale factor is computed from the transformation matrix of the bones and the influence regions. In Fig. 10.6, we have defined the modules for pre-processing (construction of the generic garment database) and online calculation that will be executed for individually sized bodies.

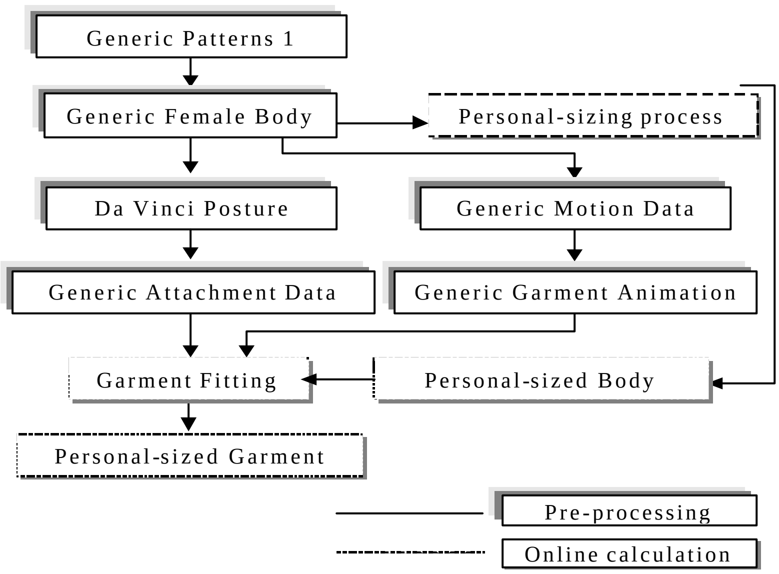


Fig 10.6. Data flow diagram for one generic female body and one specific generic pattern

User Interface of the Virtual-Try-on Web Site. The user interface is divided into three modules. First, the user is required to complete a page to define his/her measurements or to insert a smartcard containing his/her scanned data. A second page follows, where the user chooses one of the garments available in the clothes databank. Some properties of the garment can be customised, such as the texture. In the last stage, after the online processing, the user can see him/herself walking with the garment on in the virtual fitting room (Fig. 10.7). The virtual fitting room is a 3D viewer. Using the menu, the user can move the point of view and see him/herself from various angles.

The Web simulation and animation application fulfils the major considerations that determine the quality of a realistic virtual-fitting-room application, namely the quality of the animation (which depends largely on the number of frames redrawn per second), user interactivity (modification of viewing parameters, background, etc.) and response time (the most critical factor).

Our 3D models are optimised to make the whole process of dressing the customer and displaying the animations as fast as possible. By using pre-computed generic bodies and garments, we have dramatically reduced the time for online calculation. The animation of the garment provides good realism, including wrinkles, while the computation time takes no more than a few seconds.

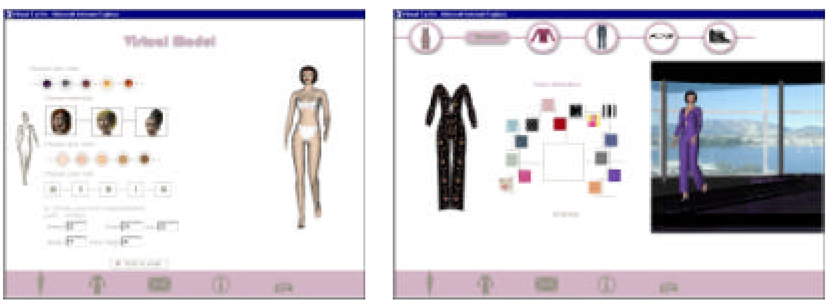


Fig. 10.7. *Left*: Body data submission window, *Right*: Garment selection – animation window

Accurate Garment Simulation on "Real" (Scanned) Customer Bodies. Creation of "Watertight" Animation Avatars Directly from Scans

An alternative to the usage of generic body models as simulation (and possibly animation) avatars is the creation of those avatars directly from the consumers' scans.

Scan data. Typically, the scan data delivered by today's 3D body-scanning systems consists of a very large set of points in 3D (more than half a million 3D points for some systems). A common drawback of optical 3D measurement systems is their inability to sample the whole body surface owing to self-occlusions of the human body (e.g. by hair, or by the arms in the area of the armpits).

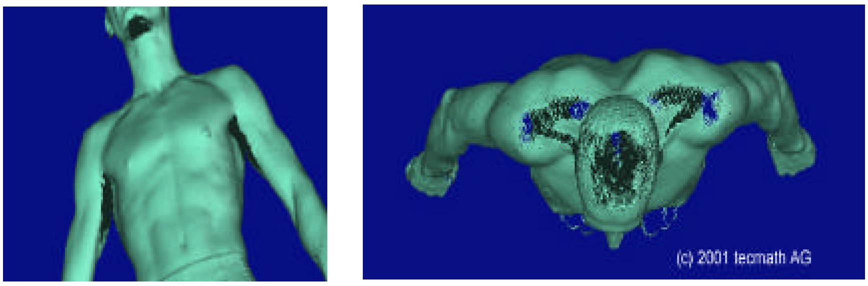


Fig. 10.8. Incomplete scan surface, as is typical of optical 3D measurement systems

Additionally, most of the systems "look" at the human body in a nearly horizontal way, resulting in a poor sampling quality in nearly horizontal body areas (e.g. under the chin and on the shoulders). An example of these effects is depicted in Fig. 10.8.

Meshing. One of the central problems in creating avatars directly from scans is to produce a "watertight skin" of the scan, i.e. a closed polygonal surface which naturally bridges gaps where no surface information is available owing to occlusion effects. While this can be done comparatively easily and accurately (though this is time-consuming) by interactive methods, the automation of this process is not straightforward.

By the development of suitable mesh manipulation tools, we were able to cut down the time required to manually produce results of a very high quality to approximately half an hour. However, for application in the MTM chain, it is necessary to be able to generate individual photorealistic customer avatars totally automatically by a simple button press. In response to this requirement, considerable effort was put into the development of algorithms for the automatic meshing of body scans. Figure 10.9 shows an initial result.

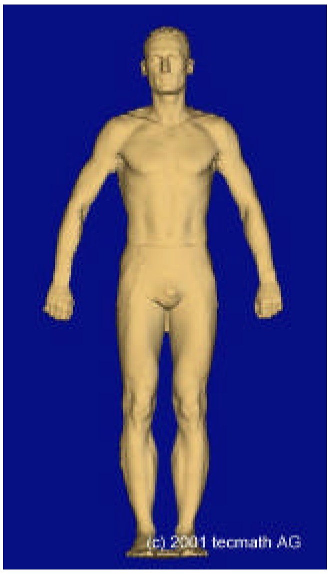


Fig. 10.9. Automatically generated body surface

In contrast to the interactive processing, the meshing process of the scan depicted in Fig. 10.9 took less than 5 minutes. Currently, the resulting mesh still displays unwanted effects due to incorrect segmentation of the scan (between the legs and under the arms). Further research will aim towards tackling this problem.

Mesh decimation. With respect to application of the avatars created in this way within the constraints of a typical Web environment (limited bandwidth and often not very powerful computers on the client side), it is necessary to reduce the polygonal mesh as far as possible to allow a sufficiently fast interaction with the model. In order to provide an optimal self-recognition for the user while at the same time obtaining a comparatively low number of polygons, curvature-adaptive mesh decimation techniques have been applied. Figure 10.10 illustrates the result of reducing an avatar surface originally consisting of over 200,000 polygons to merely 25,000 polygons.

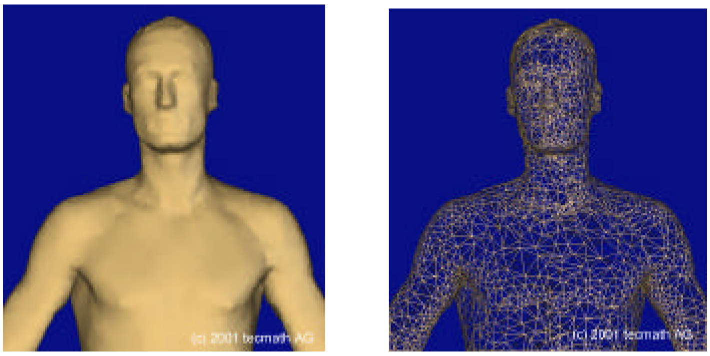


Fig. 10.10. Avatar consisting of 25,000 polygons

Dressing the scan avatars. Using a real scan from a real consumer as the mannequin figure, 2D garments produced by CAD systems are assembled on the scan mannequin, simulating the typical assembly process of the garment pieces. The assembly information is used to automate the assembly procedure on the mannequin (Fig. 10.11). The mechanical characteristics of the fabric are included in the simulation model. A static simulation result is the first step of the fitting evaluation process, which takes into account the real body position of the consumer, as well as grading and alterations made to standard patterns to produce a made-to-measure garment

Fig. 10.11. Real garment simulated on a real person

Animating the scan avatars. In order to be animated, each avatar must possess a “skeleton”, i.e. an internal kinematic structure corresponding to the bones and joints in a human being. While this arises naturally when a generic models is adapted to a scan as described above, avatars derived from scans have to be explicitly provided with such an internal structure. Additionally, methods are needed to deform the skin surface naturally when the avatar moves (e.g. in the area at the elbows).
Further research will focus on automatically equipping the scan avatars with appropriate kinematic structures, which, in combination with skin deformation

techniques and real motion sequences recorded from real persons, will allow the generation of photorealistic, highly individual avatars displaying outstanding realism.

Body Shape Classification to Derive Generic Body Models

The description of a human body shape is a complex, application-dependent task. General anthropometric classifications (somatotyping) are based on specific sets of measurements with specialised instruments (the ordinary tape being just one of them). The somatotype classification of Sheldon [5] identified three extremes of human body shape types, namely endomorph, ectomorph and mesomorph. Any individual could be considered to be composed of each of these in various proportions. Further research in this field has usually been done for anthropometric or ergonomic purposes [6] rather than for the fashion and textile industries.

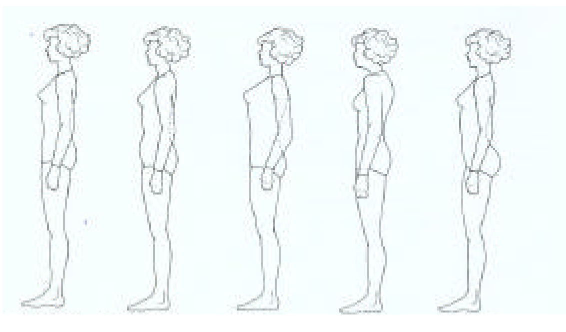
Clothing descriptors of anatomical types are more varied and less scientific, e.g. "outsize", "flat-chested" or, "pear-shaped". Information to date on body shapes is largely anecdotal and most clothing is made to fit a small number of stands, which are hoped to represent “average” sizes. The justification is historic custom and practice, with little consistency in the marketplace and continuing customer concerns about fit.

Shape analysis allows the correct averaging of body shapes which fall into a particular size category, enabling improved mannequins (real and virtual) to be made. This, in turn, should give better sizing and a better fit for mass-produced clothing.

Intelligent pattern alteration (one of the R&D tasks in E-TAILOR), will allow shape analysis software to be combined with expert knowledge of traditional pattern cutting. 3D scanned body shape data will provide an electronic mannequin for an individual. This will link to clothing CAD/CAM systems, taking user style preferences into account, to produce made-to-measure fashion.

Figure 10.12 illustrates a set of female body morphologies (postures), which affect the balance and fit of garments, irrespective of size. Since the intelligent pattern alteration subsystem will focus on alterations for ladies' garments, the detection and classification of these postures will be the main objective of the shape analysis and classification research. As depicted in this figure, the features of interest relate mainly to the shape of the shoulders, hips, abdomen and back.

The following methodologies for achieving automatic shape classification are being explored:



a b c d e

(a) Correct posture (b) Protruding abdomen (c) Overly erect back

(d) Rounded upper back and shoulders, forward head (e) Swayed back, forward pelvis tilt

Fig. 10.12. Female posture types relating to back, abdomen and pelvis areas [7]

- Identify the required direct measurements and/or suitable combinations of measurements, evaluate them and include them in the measurement set to be used for made-to-measure production (individual alterations).
- Identify cross-sections that are informative about shape, model them, and produce combined and normalised shape attributes. Evaluate these attributes for all samples of a statistically significant, i.e. representative population, according to certain criteria. Cluster the derived attributes in the shape attribute space and perform supervised classification, i.e. train a classifier to identify the required shape classes (supervised learning). Repeat the above loop for various sets of attributes to identify a set that corresponds in an optimal way to the perception of the above shape classes by a human expert.
- Identify (segment) the relevant body surface patches and produce a generalised shape representation. Robust shape modelling and subsequent classification can be achieved by the use of active shape models (ASMs) [8]. This technique is based on the automatic identification of landmarks (well-defined points that can be robustly identified on the body surface) on all members of a sample set of 3D bodies. Alignment and subsequent statistical analysis of the relative distribution of these landmarks (point distribution model) can provide "average" shapes, along with the principal modes of shape variation observed in the sample. These can lead to automatic classification of body shapes.

Storage of Body Data in Multi-Application Smartcards

Creating virtual 3D images of each of us on the Internet causes problem of privacy which must be tackled immediately before such an application is promoted to consumers. The best solution is certainly the local storage of any private data (e.g. 3D body) on smartcards.

Java card technology offers a way to overcome the obstacles hindering smartcard acceptance. Essentially, Java card technology defines a secure portable, multi-application smartcard platform that incorporates many of the advantages of the Java language.

The research and development undertaken in E-TAILOR will feed into smartcard-based products with the following innovative features:

- The products will be portable across a wide range of hardware/software architectures, including embedded devices and mainstream e-commerce applications.
- They will be portable across a wide range of points of sale – phones, PDAs, kiosks, public communication terminals and PCs.
- They will offer a combination of security and XML-based data definition, storage and retrieval on a multi-application smartcard.
- Body shape data will coexist with existing payment applications without compromising the privacy and security of the customer or the vendor.

Conclusions

The E-TAILOR programme is founded on a global approach, global in terms of tackling the main problems related to virtual retailing of customised garments, as well as global in terms of establishing a critical mass of major European actors in the related fields and technologies.

Besides its innovative approach to many aspects of project developments (realistic 3D virtual try-on linked to CAD data, virtual prototyping based on scanned bodies, body shape analysis and classification, intelligent pattern alteration and storage of body data on smartcards), the impact of the project is expected to derive mainly from its global approach (technology integration, standard representations and interoperability).

The impact is expected to be quite significant for all segments of the clothing industry and fashion retailing industry (infrastructures and standards to support size harmonisation; innovative, interactive visualisation and product description technologies to increase customer confidence in buying clothes online; and integration of critical steps and data for handling and fulfilment of orders for made-to-measure garments).

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