3D DESIGN AND SIMULATION OF MEN GARMENTS

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ABSTRACT

This paper outlines a 3D graphic environment to design and simulate men garments according to fabric properties and manufacturing processes. The aim is to permit the design in 3D of men base garments, in particular jackets, together with evaluation of their styles and automatic generation of 2D patterns from the 3D representation. 3D garment design has been based on the use of MAYA? (Alias/Wavefront) Deformers, while simulation relies on particle-based approach. Main modules of the system are described as well as methodologies and techniques adopted. The prototype has been experimented by end-user; results and final considerations are reported.

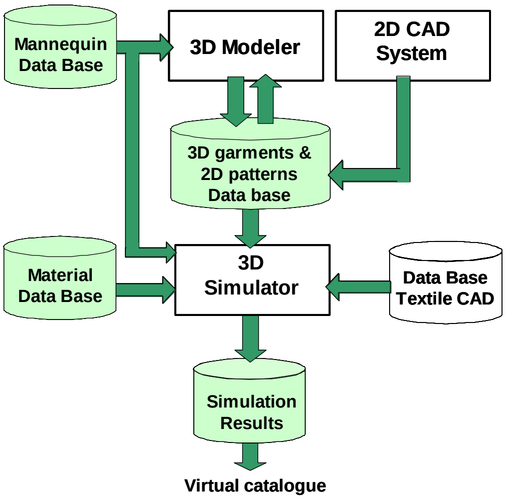
Keywords: clothing design and simulation, industrial application, particle-based model.

1. INTRODUCTION

Clothing manufacturers require systems with the capacity to deal with garment design process as a whole, including possibilities to work directly within a 3D graphic environment

In such a context, the aim of our research work has been the development of a graphic and interactive environment to design men garments and simulate their behavior according to fabric properties and manufacturing processes. The system should permit to predict the real garment behavior acting on the parameters characterising its physical model in order to reduce the number and the role of the physical prototype. This kind of tool has not to be confused with other research prototypes or systems currently available on the market (e.g. MAYA? , Alias/Wavefront) since they are mainly oriented to animation and applications, such as movies, cartoons, or virtual catwalks.

Figure 1 shows the reference architecture of a 3D system for garment design and simulation. We can distinguish two modus operandi according to garment types, design process, and strategies adopted within manufactures companies.



Reference architecture
Figure 1

First one involves drawing 2D patterns by using 2D CAD systems. Modules have to be developed to generate, starting from 2D patterns, data necessary to define the 3D physical model of the garment and execute the simulation.

The latter, more innovative, consists of the design of 3D garments around a digital mannequin. This technique is more natural and creative because it allows direct transference of the garment concept. The modelist uses 3D graphic tools, the 3D Modeler and the 3D Simulator, to both design and simulate the garment. 2D patterns are automatically generated as well as data for assembling and positioning 2D patterns around the mannequin to define the physical model.

We followed the second approach, even if different solutions have to be adopted for men and women garments.

2. THEORETICAL BACKGROUND AND PREVIOUS WORKS

In the field of CAD/CAM, computer based systems have been developed to assist the modelist. There are systems that allow the modelist to design 2D patterns, sew them together, and put them on a 3D mannequin, thereby using physical techniques to provide an estimate of their wear-ability. Regarding garment design, industrial packages, such as the PAD system (www.padsystem.com), or research tools (www.cadcam.ust.hk/research/garment.html), [Carignan92], (www.ercim.org), [Provot97a] [Imaoka84] [Okabe92], use this methodology to develop 3D garments and 2D patterns. Only a few research teams, such as [Hinds90] [McCartney99] and the University of Valenciennes [Bonte00], work on 3D garment design by employing geometric techniques to model the 3D garment and generate 2D panels.

Regarding simulation, the critical issue is the physical model to represent and simulate the garment. Several techniques can be found in literature to model and simulate fabric. They can be distinguished in: *geometry-based*, *physically based*, and *hybrid* [Cugini99]. Physically based models, in particular discrete ones, seem to be the best solution. Among the discrete models, the particle-based one, force-based version, is the most known and used within research communities for fabric modeling and simulation [Breen94] [Carignan92] [Eberhardt96] [Hing96] [House98] [Siggraph98] [Volino96] [Volino97]. Particle based model permit to represent, at macroscopic level, fibers braiding.

By this approach, an object is described as a set of particles and forces acting on the particles. The internal forces model the mechanical behavior of material. The simulation is carried out using the Newton law: $\boldsymbol{f} = m\boldsymbol{a}$. The resulting mathematical model of a particle system is a system of second order ODE that can be reduced to a first order equivalent system and, therefore, solved step by step with numerical integration.

However, simulating the behavior of a deformable object, like fabric, is not sufficient to consider only internal forces; we must also manage interactions between the object and surrounding environment. We have taken into considerations:

- *External forces,* such as gravity and aerodynamics forces, treated as the internal ones;
- *Constraints* that restrict the movements of an object (conditions that must be respected by the object during its motion);
- *Collisions with obstacles*, for example, when a flexible object hits a rigid object (the mannequin) or penetrates itself (fabric self-collision).

There are different methods for constraints handling [Platt88] [Witkin90] [Fleisher87]: *Penalty method*, *Lagrangian Constraint*, *Lagrange multipliers*, *Rate-controlled constraints*, and *Dynamics constraints*. We implemented the Dynamic constraint method, since it permits to apply multiple constraints to the same particle and ensures the respect of all the constraints at each step of the simulation.

Collision management involves two aspects: *collision detection* and *collision response* [Cugini99]. The first is often the bottleneck of deformable objects simulation systems handling highly discretised objects, as happens for our application, and heavily influences computational times (up to 95%). Usually, instead of detecting collisions for each object (described by a set of particles) against all other objects, optimisation techniques have been introduced in order to reduce computational time.

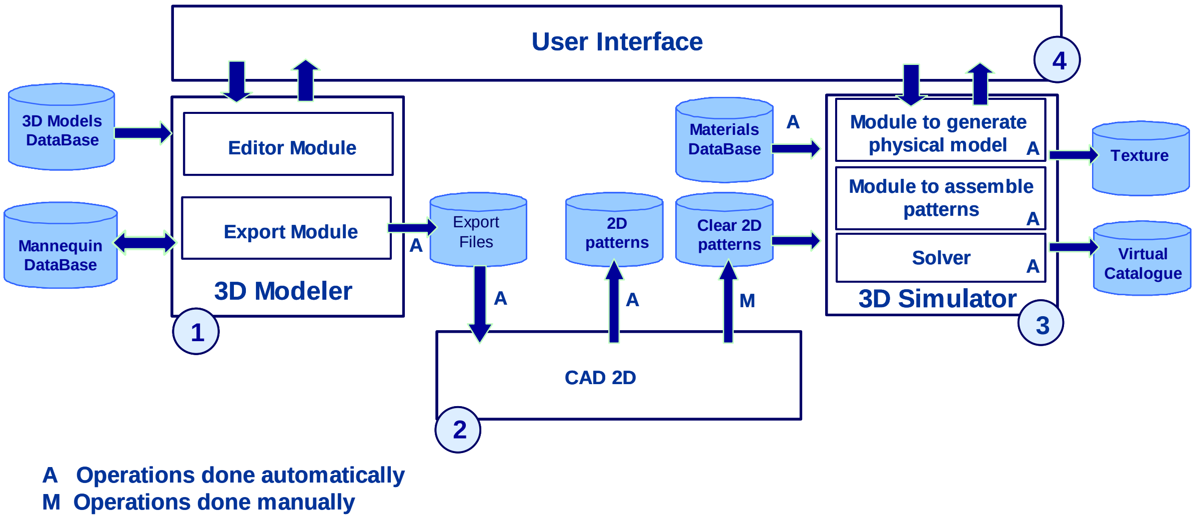
Some techniques for collision detection optimisation are [Volino94] [Provot97b] [Cugini99]: *Voxel subdivision, Octree subdivision, Bounding box hierarchy, Proximity tracking,* and *Curvature – based*. We adopted the third one, a good compromise between simplicity and efficiency. By this technique, objects are grouped hierarchically according to proximity rules, and the detection is carried out by exploring bounding box intersections in the hierarchy. Moreover, since garment fabric could self-collide, objects have been splitted into sub-parts and the bounding box of each part is considered.

A further improvement has been reached *decoupling detection and response.* It comes from a simple idea: the simulation step is so small that it is not necessary to search for new collisions at each step. During the ODE step, it is easy to find the velocity of the speediest particle. In the worst case, this particle is close to collision with a triangle, the distance between the two being only a little larger than the threshold value, *dp*. Computing the time *tc* needed for this particle to cover half of *dp*, we can be sure that no undetected collisions will lead to a penetration in the next *tc* seconds. It is possible to make a more conservative computation of *tc* based on a quarter or less of *dp* or to be more aggressive using bigger fractions.

3. THE DEVELOPED SYSTEM

Figure 2 shows the main components of the software environment developed:

1. The *3D Modeler* that possesses all the necessary functionality to edit (*Editor Module*) men garment according to traditional designer's working method and to automatically generate (*Export Module)* data for 2D patterns representation, necessary for garment simulation and manufacturing;
2. The *2D CAD system* used to produce, using above mentioned data, the 2D patterns of the 3D designed garment;
3. The *3D Simulator* that consists of three main modules: the Module *to generate physical model* for defining the particle model of 2D panels according to fabric properties, the *Module to assemble patterns* for sewing and assembling 2D patterns over the mannequin (i.e., the initial 3D configuration), and, finally the *Solver* for executing the dynamic simulation;
4. The *User Interface* that proposes a unique environment for both the Modeler and the Simulator. It has been designed to be as close as possible to traditional design process and based upon the designer's knowledge.



System architecture
Figure 2

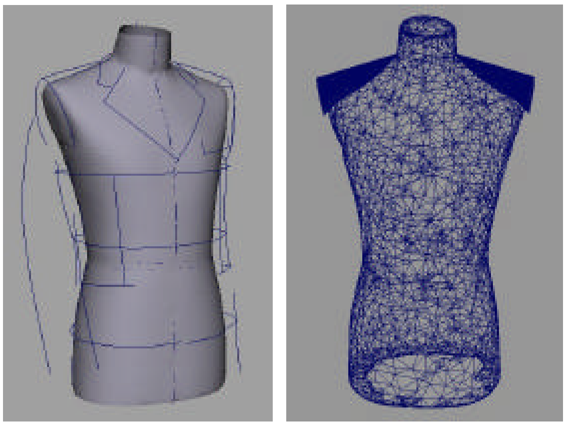
Component 1, 3 and 4 have been completely implemented by our research group, while component 2 is a 2D commercial CAD system. The 3D Modeler (in particular the Editor Module) and the User Interface has been implemented using the commercial package MAYA? Alias/Wavefront.

3.1 3D MODELER

The design process currently followed within companies has been analyzed in order to extrapolate functionalities of the Modeler. As reference garment, we selected a jacket since it is considered the most representative men cloth. Typically, the designer creates a new style by modifying the shape of a physical prototype, e.g., changing sleeves length or tightening the waist, according to fashion trends and stylist's sketches. To do this the designer uses reference elements: sewing lines, significant and structural elements, such as waist or shoulders. Therefore, the Modeler had to permit the designer to operate in the same way using a digital prototype instead of a physical one. This required the acquisition of the mannequin and jacket geometry to be used as reference shape from which derive new ones by interactive changes.

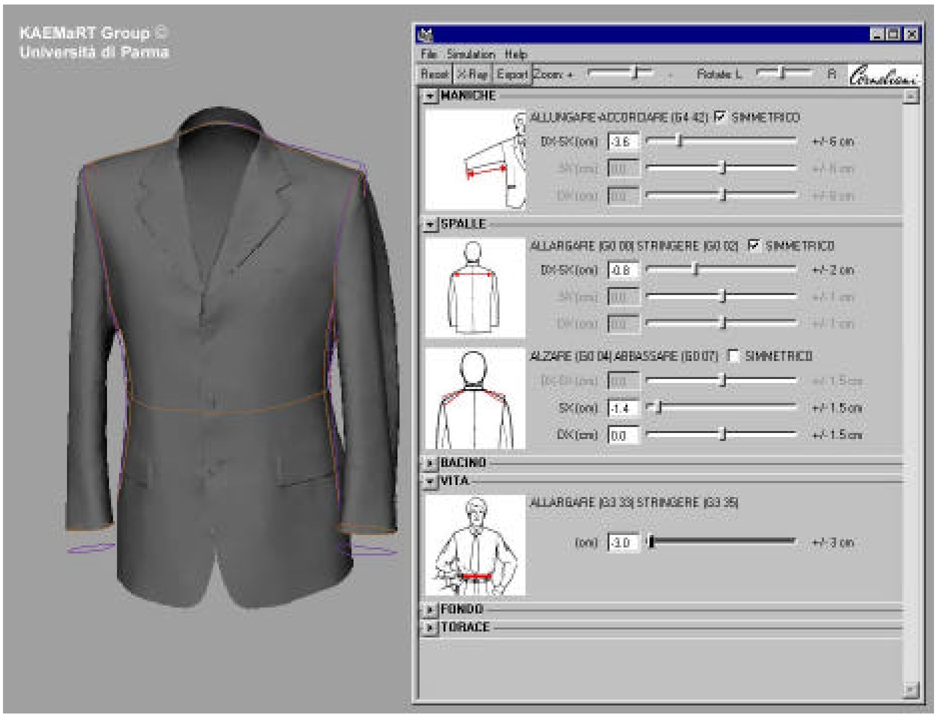
ATOS (Advanced TOpometric Sensor) (http://www.gom.com) technology has been used to digitise the mannequin, the jacket and reference lines necessary for both the Editor Module and the Simulator. Acquired point clouds have been elaborated with reverse engineering techniques using the package PARAFORM, Paraform Inc. (www.myb2o.com). Main problem has been to find a good compromise between geometric model accuracy (avoiding loose of details) and memory occupancy; this because the designer would like to evaluate the results of his/her changes in real time.

Moreover, for the Simulator, mannequin with shoulder-padding has been digitized. Figure 3 shows acquired lines and the geometric model of mannequin with shoulder-paddings.



Reference lines and mannequin for simulation
Figure 3

The Editor Module has been implemented using and combining MAYA *Deformers* [Maya00], which enable the user to change the shape of a geometric model. From the analysis of modelist's modus operandi, we have identified and implemented a set of modifiers that permits the designer to perform traditional modifications. Some examples are: shorten/lengthen sleeves, tighten/enlarge shoulders, tighten/enlarge waist, shorten/lengthen jacket. For each type of modifier, we have identified the interaction style and allowable range of values.
Figure 4 shows the Editor module, related user interface and some of implemented modifiers.



MANICHE

ALLUNGARE-ACCORCIARE (G4 42) ☑ SIMMETRICO

DX-SX (cm) -3.6 +/-6 cm

SPALLE

ALLARGARE (G0 00) STRINGERE (G0 02) ☑ SIMMETRICO

DX-SX (cm) -0.8 +/-2 cm

ALZARE (G0 04) ABBASSARE (G0 07) ☐ SIMMETRICO

SX (cm) -1.4 +/-1.5 cm

DX (cm) 0.0 +/-1.5 cm

VITA

ALLARGARE (G3 33) STRINGERE (G3 35)

(cm) -3.0 +/-3 cm

Editor module
Figure 4

3.2 3D SIMULATOR

As already said the 3D simulator is based upon the particle-based approach. As shown in Figure 2, it possesses all the necessary functionality to:

- Import the mannequin used by the modelist to design the 3D garment;
- Automatically generate the particle model of 2D panels according to material properties;
- Position and assemble 2D patterns over the mannequin using data generated by the 3D Modeler and acquired by digitalisation;
- Execute the simulation.

The prototype proceeds according to the following steps:

1. 2D garment patterns are discretised according to the particle-based approach and warp-weft directions;
2. Forces among particles and corresponding parameters value are established on the basis of fabric mechanical characteristics;
3. 2D patterns are sewed using reference lines and assembled over the mannequin in order to reach an initial configuration;
4. Garment's behavior is simulated.

In the following, the generation of jacket physical model (1-3) is described.

3.3 GENERATION OF THE PHYSICAL MODEL

Based upon previous experiences gained with women garments [Bonte00], we made following assumptions:

- A simplified model representing the fabric as composed by a single equivalent layer;
- Simulation of multi-layered parts acting only on parameters characterizing their behavior without considering thickness;
- Final configuration depends only on the 2D geometry of patterns and mechanical properties of considered type of fabric (cotton, woven, silk, etc.);
- Use of KES (Kawabata Evaluation System) measurements [Kawabata80] to characterise fabric and multi-layered parts (the front of the jacket) composing the garment;
- Use of geometric data not only for 2D patterns profiles, but also to position buttons, collar and lapel pleats.

First step requires the generation of “*cleared*” 2D patterns; this means we have to eliminate exceeding fabric necessary to manufacture the garment.

Then, it is necessary to make 2D patterns discrete according to the adopted model, define the distribution of forces, and sew the 2D panels.

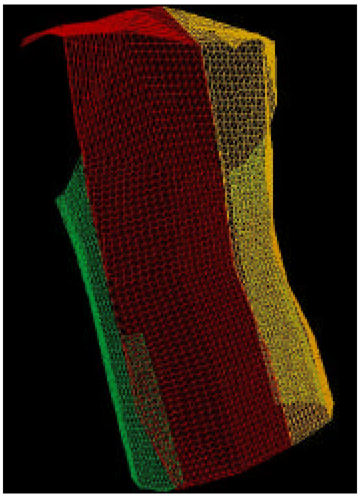
We discretised each 2D pattern with a *rectangular grid* of *particles* having a grid step of 10 mm. When dealing with fabric-like material, as in this case, the two directions of the grid model the warp and weft directions. Material anisotropy can be simulated by characterising differently the forces along the two directions. Particular attention has been paid to 2D panel edges to allow the subsequent production of seams with other panels. First, a particle is placed at each vertex of the 2D pattern contour; then particles are added along the pattern edges to have roughly the same resolution present in the inner part. The algorithm splits edges recursively based on the grid step. The particle mass is computed through the analysis of fabric density derived from KES measurements.

Because of the experiences carried out in other industrial projects [Bonte00] [Cugini99] [Rizzi00], following forces have been considered: stretching and repelling, bending and trellising (shear) forces. Springs and bending forces have different characterisation in warp and in weft directions. For mechanical characterization, we used Kawabata measurements related to *weight, elongation*, *bending* and *shear* since they can be easily correlated with parameters describing forces.

Finally, using data (seaming lines) acquired through digitalization, each panel is correctly sewn and placed around the mannequin.

To sew a pair of panels, the edges identified as seaming lines must have the same number of polygon segments with the same length. The discretisation algorithm developed takes into account this problem and two panels can be sewed welding them along the seaming line. The particles on the border of first panel are deleted and replaced with particles on the border of the second panel. Spatial positions and assembly rules of the 2D patterns have been derived from the 3D digitised model of the jacket. Figure 5 shows some patterns sewed together.

Described operations, from particle model generation to finally assembly around the mannequin, are automatically executed by the system for each new jacket designed by the modelist.



Patterns sewed together
Figure 5

4. SYSTEM EXPERIMENTATION

Validation and assessment procedures have been defined and both modules have been assessed by the end-users.

For the experimentation of the 3D Modeler, we have selected three types of jacket, considered the most meaningful by the end-users. The end-users evaluated positively the module, mainly for what concerns the user interface since it required a short training and low level of competence in using geometric tools.

Some possible enhancements concern introduction of new editing tools and the possibility to apply the defined modifiers directly to the simulated garment.

As far as the simulation is concerned, the procedure is performed automatically and level of user interaction is very low. During a first set of test, some drawbacks have been highlighted mainly due to initial assumptions done for the garment physical model (see §3.3). The results of the simulation were not coherent with the real garment behavior; this was not related to the approach adopted or to simulator performances, but to the simplified characterization we adopted for some structural parts of the jacket whose behavior depends also on manufacturing processes. In fact, we didn't consider the influence of manufacturing processes, such as ironing, dressing, and special sewings, we initially considered marginal.

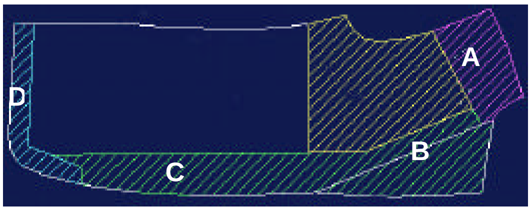
Figure 6 shows some results obtained during first phase of the experimentation. Figure 6b portrays the digitized model of the jacket; Figure 6a the simulation of the jacket without considering lining (see the bottom of the jacket) and with only one shoulder-padding; Figure 6c the simulation of the jacket obtained considering the influence of lining. Analyzing the results and the images, we observed that the simulation was correct from the physical point of view, but since we didn't include in the model of the jacket mentioned topics, e.g., manufacturing processes, the results were not adequate for the modelist.

Therefore, we had to enrich the garment physical model introducing new operators/parameters in order to be able to simulate permanent material deformations (e.g., lapel pleat) obtained with manufacturing processes, such as dressing.

Simulation results: first tests
Figure 6

4.1 REFINED PHYSICAL MODEL

To overcame above mentioned drawbacks, the 2D patterns and the physical model have been subdivided into regions, each one corresponding to a structural part of the jacket, e.g., shoulder, facing, and collar. Each region is characterized by different physical parameters, which integrate mentioned effects. Figure 7 shows the 2D pattern corresponding to the right front of the jacket and related regions: (A) shoulder, (B) pleating line of the lapel, (C) facing, and (D) bottom of the jacket.



Right front 2D pattern and related regions
Figure 7

A stand-alone simulator, named *Textile Lab*, has been implemented to allow the modelist to interactively modify mechanical parameters associated to each region, and execute garment simulation.

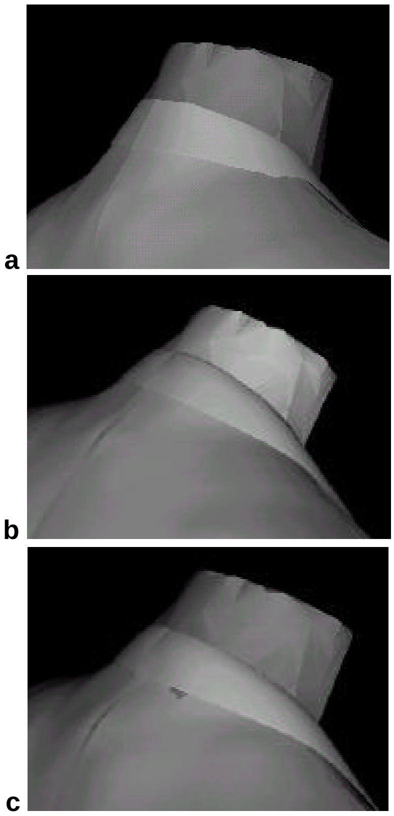
In collaboration with the end-users, a new set of simulation tests has been performed. For each region, we proceeded varying associated parameters by means of multiplicative factors, and using KES measurements as basic values. Thus permitted us to characterize each single region and reach simulation results judged good enough by the modelist.

Main goal of this experimentation phase has been to verify the feasibility of our approach (jacket subdivision into regions). We systematically analyzed the regions, starting from those with more problems:

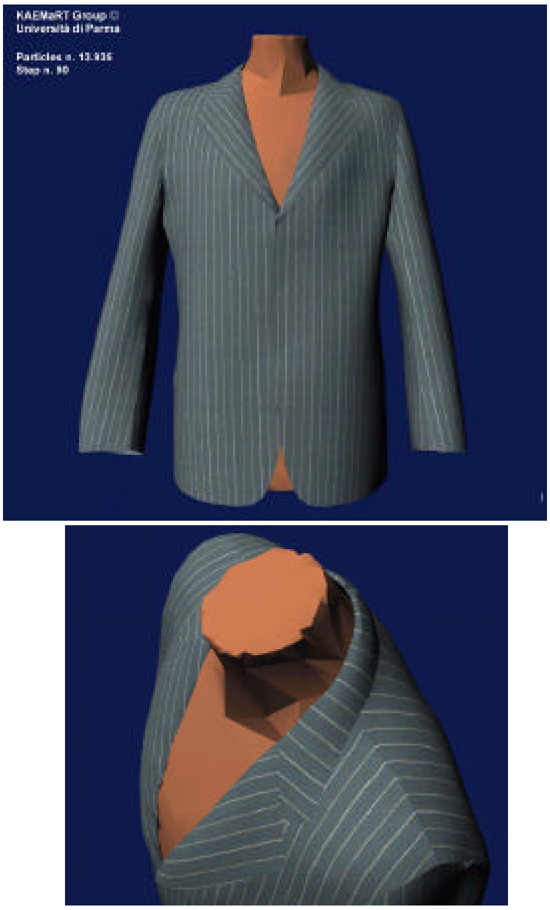
- *Collar and lapel* to better characterise pleats;
- *Arm-hole*, to make uniform
- both front and back behavior;
- *sleeve*;
- *Bottom of the jacket, taking* into account the presence of facing and ironing.

Figure 8 shows some simulation results obtained for *collar* region. In Figure 8a, one can note that the collar is too flat, while in Figure 8b-c the behavior appears more correct and coherent with the real one. In these cases, we changed parameters associated to the region collar, such as pleat bending parameter.

Figure 9 portrays and image of the simulated jacket with fabric texture and a detail of collar and lapel.



Simulation results – collar region
Figure 8



Simulation of the jacket
Figure 9

5. CONCLUSIONS

The system has been developed experimentally for the design of men garments. Validation and assessment procedures have been defined and both modules have been assessed by the end-users. The following considerations can be summarised.

As far as the 3D Modeler is concerned, the end-users evaluated the module positively since it does not require any specific knowledge on geometric modeling and does not present any difficulties. Some enhancements have been found out mainly related to the extension of types of editor operators, i.e., shape/volume changes.

Regarding the 3D Simulator, the procedure is performed automatically and level of user interaction is very low, once selected the fabric type. In collaboration with the end-users, we carried out two different series of simulation tests. During the first simulation phase, some limits have been identified mainly due to jacket physical model that was too simplified. Therefore, we defined a refined physical model subdividing the garment into structural regions and considering the effects of manufacturing processes such as ironing and dressing, not considered in the first model. The results are encouraging, although simulation times increase rapidly and further improvements are necessary; on the other hand, a jacket can be considered one of the most complex garments. We envisaged the need to execute further KES measurements on specimens of the jacket structural parts, e.g., fabric+lining, in order to get results that are more precise.

A critical issue is the calculation time. The modelist would like to see the results of the simulation in few minutes in order to be able to compare the effects of different fabric and styles. Simulation time can be dramatically reduced implementing a parallel algorithm. A parallel version of the particle-based simulator is under development for a Beowulf cluster and we are obtaining a good reduction of computational time. At present, only the collision detector has been parallelised, but the results encourage us to perform further efforts to reduce the computation time for an effective computer-based garment design and simulation

The Simulator has been also experimented for woman garments, even if different 3D modelling strategies have been adopted [Bonte00], and for automatic handling of non-rigid products (e.g. wire, and car soft-top) [Rizzi00].

The results are encouraging and they demonstrate that the prototype and the approach are effective for representing and evaluating the behavior of non-rigid materials for a wide range of industrial applications, from automotive to food and clothing industry.

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