Computers in Industry 61 (2010) 576–593

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

A survey on CAD methods in 3D garment design

Yong-Jin Liu [a,*], Dong-Liang Zhang [b], Matthew Ming-Fai Yuen [c]

[a] Department of Computer Science and Technology, Tsinghua National Lab for Information Science and Technology, Tsinghua University, Beijing, China
[b] Livesforce Co. Ltd, Hangzhou, China
[c] Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Hong Kong, China

ARTICLE INFO

Keywords:
Garments
CAD methods
Feature modeling

ABSTRACT

With the advance in virtual reality applications, garment industry has strived for new developments. This paper reviews state-of-the-art CAD methods in 3D garment design. A large range of techniques are selected and organized into several key modules which form the core of a 3D garment design technology platform. In each module, basic techniques are presented first. Then advanced developments are systematically discussed and commented. The selected key modules – digital human modeling, 3D garment design and modification, numerical integration of draping, 2D pattern generation, geometric details modeling, parallel computation and GPU acceleration – are discussed in turn. Major challenges and solutions that have been addressed over the years are discussed. Finally, some of the ensuing challenges in 3D garment CAD technologies are outlined.

1. Introduction

Garment CAD technology is the use of computer technology to assist the design of garment product. Compared to other mechanical product, garment CAD has to address some special issues. Firstly, it models soft material with low bending stiffness rather than rigid solid objects. Secondly, garment components such as collar and sleeve, are assembled together following specific pattern-making rules which are totally different from the conventional assembly methods. Thirdly, while the garment is constructed from 2D patterns, the quality of fit is evaluated on 3D human models. Based on these observations, garment CAD is a unique research area that has attracted considerable attentions.

Early garment CAD focused on 2D pattern drafting and modification. The pattern-making techniques in 2D CAD systems mainly consist of two parts [117]: (1) individual pattern generation based on parametric design; (2) individual pattern altering based on grading rules. Since garment is more flexible than other industrial products, the constraint types used in both parametric design and the grading rules depend on pattern makers' experience which is case-sensitive: for example, different experiences are needed for different apparel patterns such as suit, jean and shirt. The well recognized flowchart of 2D garment CAD systems go through the phases of fashion style design, pattern design, pattern grading and marker making. Some typical commercial softwares of 2D garment CAD include Toray-Acs in Japan [111], Gerber in United States [112], Investronica in Spain [113], Lectra in France [114].

To release the heavy dependencies on pattern-masters' experience in 2D systems, 3D garment CAD methods with the technologies of human body measurement are studied and proposed as an alternative solution to non-expert users. The key techniques include 3D human body measurement and modeling, 3D garment design on digital human models, 3D draping simulation, and 2D pattern generation from 3D space. Two well known commercial softwares of 3D garment systems are Assyst-Bullmer in German [115] and Dessingsim in Japan [116].

Garment design and simulation are intensively studied in the fields of both computer graphics and computer-aided design. In this paper we present a detailed survey on CAD methods in 3D garment design, showing their promising characteristics and their relationship to 2D CAD methods. For the state-of-the-art techniques in garment animation and rendering, the reader is referred to the monographs [47,100] and the excellent survey work in [22,97]. This survey is partially based on the authors' experience on building the 3D garment CAD system developed at the Hong Kong University of Science and Technology. The second author also co-organized the ACM SIGGRAPH'05 Course Notes [22], from which some material presented here comes. The overall structure of this paper is aimed at presenting a systematic view of development of the 3D garment CAD platform.

This paper is organized as follows. Section 1 covers the introduction of 2D and 3D Garment CAD platforms. Section 2 presents the basic approaches. Section 3 describes the human modeling and Section 4 covers the garment models. Section 5 details the draping methods and Section 6 outlines the 3D to 2D pattern

* Corresponding author.
E-mail addresses: liuyongjin@tsinghua.edu.cn (Y.-J. Liu), livesforce@yahoo.com (D.-L. Zhang), meymf@ust.hk (M.-F. Yuen).

0166-3615/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.compind.2010.03.007

transformation. Section 7 reviews the geometric detail modeling approaches and Section 8 summarizes the parallel computation and GPU acceleration techniques. Section 9 provides a perspective for future directions and Section 10 concludes the review.

2. Basic approaches

In this section, we outline the basic approaches in 3D garment design. Based on this foundation, in subsequence sections, we will review incremental progresses towards some more advanced CAD methods in garment design.

2.1. Feature-based human body modeling

With the advance of 3D scanning techniques, the individualized human body can be easily captured and modeled with a mesh model [1]. In addition to geometric definition of the human model, it is necessary to use semantic features to facilitate the garment design on the model. Assume that the model is in a normal pose (we will review the techniques in Section 3.2 how to release this restriction). In the middle of Fig. 1, two sets of sizing parameters are used to characterize the human body: the heights h_i specify a set of cutting planes parallel to a base plane in the model space, and the girths g_i are measured on each cutting plane intersecting the human body. The cutting planes are used to build a classification on the vertices, edges and faces in the body mesh model such that each of them is associated with a semantic feature in the set $\{head, neck, shoulder, chest, bust, waist, hip, leg, foot, etc.\}$ (see the left of Fig. 1). The segmentation of human body model also leads to a natural parameterization of the model which can automatically provide accurate measurement of the individual model (see the right in Fig. 1).

The segmentation process (or in other words, cutting plane determination) usually makes use of some rules of thumb: for example, anthropometry shows that body height equals to eight head tall [82]. The special characteristics of the human body are also helpful to establish the locations of cutting planes. These characteristics include neck points, underarm points, busty points, belly-button point and crotch point, etc. For example the crotch point is the point starting from which the cross-section of the body changes from one circle to two circles. So a simple and effective way to determine crotch point is to cut the body at 5/8 total height from the top [122]. Refer to Fig. 2. In the cross-section, the intersection points are sorted and the maximum gap between two neighboring points (denoted by P_l and P_r) separate the left and right legs. At the middle $P_o = (P_l + P_r)/2$, a perpendicular plane is setup. The lowest intersection point of this plane with the body is the crotch point. More comprehensive and innovative CAD methods for human body segmentation will be presented in Section 3.

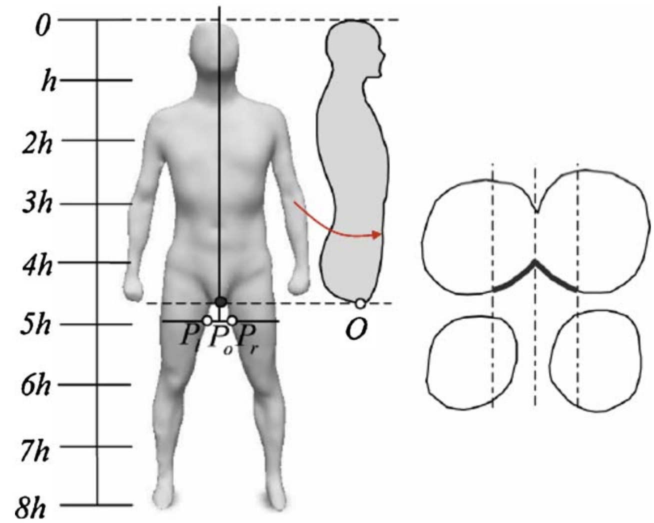

Fig. 2. Crotch point determination [122] (courtesy of Prof. Bugao Xu).

2.2. 3D garment design and modification on human model

Given the human model with detailed semantic features, traditional procedure of a pattern maker can be mimicked by using computers. A case study of ladies' dress design is presented in [74]. Let the human model be oriented such that it stands on the *xy* plane, the *xz* plane cut the body into left and right parts, and the *yz* plane cut into front and back parts. Refer to Fig. 3. The shoulder seam is defined as a line segment connected by points 1 and 2 which is in the intersection of the body and the plane P_{side} parallel to the *yz* plane and towards back about 20 mm. The same plane P_{side} defines the points 3, 5, 6 in the side seam of the dress as well. The point 4 is defined on the planar curve of the waist which move forwards in the waist by 20 mm. The points 3, 10, 18 are on the curve of chest, 4, 9, 19 on the waist and 5, 8, 20 on the hip. I.e., each point is related to a semantic feature on the human body. The closed curves at the cross-sections of the chest, waist and hip circumferences of the dress are determined by enlarging the intersection curves. The enlargement determines the tightness and fitness of the dress over the human body. The final dress is made up by adding more auxiliary curves and points which is also determined by rules related to the known points 1–25 in the dress and the semantic human model. Given such a set of deterministic rules, for any customized human model, the corresponding customized dress is determined immediately.

The 3D garment on human body can be further modified using virtual scissor in computer [89]. The widely used tool is provided by OpenGL with the interaction functions. The users can pick point,

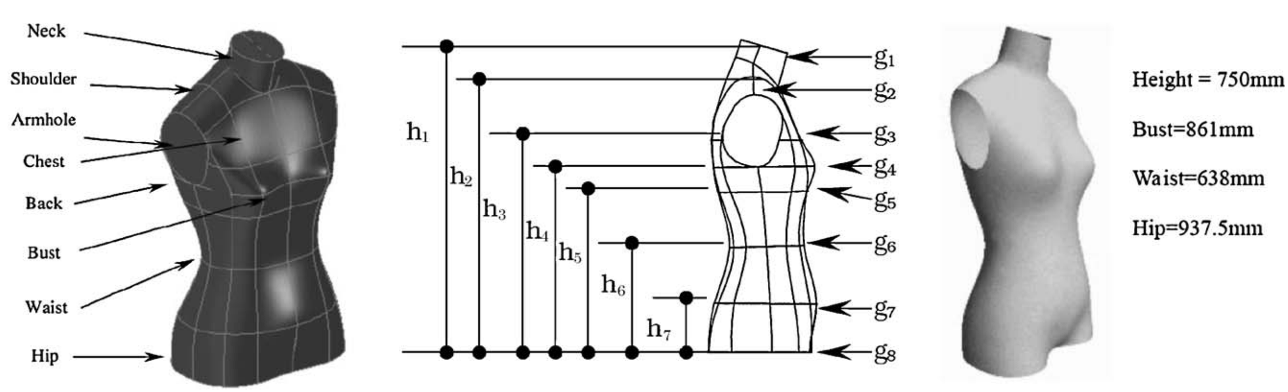

Fig. 1. Human body modeling and segmentation with semantic features [6,7] (courtesy of Prof. Matthew Yuen).