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Overview of Personalized 3d Human Body Modeling Technology for Garment CAD

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Abstract: 3D human models serve as the foundation for 3D garment design, while personalized human modeling has emerged as a significant research focus in computer graphics and computer vision. Over time, numerous implementation approaches have been developed. This paper reviews and summarizes recent advancements in personalized human modeling, categorizing them into scanning-based methods, standard model deformation techniques, template matching approaches, image-based model reconstruction, and wireframe-assisted deep learning methods. The study analyzes the strengths and limitations of existing methodologies while outlining future development trends.

Keywords: Garment CAD; 3D human modeling; Personalized.

1. Foreword

3D human models serve as essential foundational data for film production, gaming, 3D garment CAD, virtual fitting, and digital customization. The primary challenge in developing personalized 3D human modeling technology lies in achieving rapid, efficient, accurate, and user-friendly generation of models that accurately match clients' body types within current computer hardware and software environments [1]. The evolution of human modeling has transcended computer graphics research, now incorporating advancements from robotics, artificial intelligence, computer vision, and machine learning disciplines [2].

Current personalized 3D human modeling methods primarily include scanning [3], standard model deformation [4-9], template matching [10], image-based model reconstruction [11-12], and wireframe-assisted deep learning [13]. The standard model deformation method achieves personalized human modeling by applying deformations to standard model templates based on human features. The template matching approach stores all parameterized human models in a digital database, identifies the closest match through template alignment using user parameters, and fine-tunes the model to create a customized version. The orthogonal image method reconstructs detailed geometric features by extracting limited-sized characteristics from clients' orthogonal view photos. The wireframe-assisted deep learning modeling method segments the human model into smaller components using feature wireframes, applies PCA dimensionality reduction, and utilizes deep learning to correlate these features with semantic parameters for personalized modeling.

Due to the complex and diverse shape of human body, the robustness, accuracy, spatial complexity and time complexity of existing personalized modeling methods can not be guaranteed. At present, there is no modeling method that can accurately and quickly reproduce three-dimensional human body model.

2. Related Work

Digital 3D human modeling, a fundamental research area in computer graphics, focuses on simulating realistic human forms through computational technologies. This technology finds extensive applications in film production, gaming, virtual fitting systems, fashion engineering, and ergonomics. Personalized 3D human modeling enables rapid and precise recreation of three-dimensional human models based on user-defined specifications or measurements. However, due to the inherent complexity of human anatomy and diverse body movements, existing methods often lack robustness, accuracy, and efficiency in terms of time and spatial complexity. This paper conducts a literature review of recent advancements in personalized 3D human geometry modeling techniques, evaluating these methodologies through their distinctive modeling approaches as key differentiators.

The study [3] employed three Kinect depth cameras for personalized human reconstruction. The algorithm utilized thickness-insensitive pleated paper to calibrate the three Kinect devices geometrically, enabling simultaneous automated scanning from three perspectives of the subject to reconstruct model surfaces. While demonstrating strong user-friendliness and operational simplicity, the reconstructed models exhibited relatively low precision, with subsequent processing still requiring considerable time.

Reference [4] employs a feature-based parametric deformation method that iteratively modifies waist circumference contours using predefined deformation ratios based on user-specified anthropometric measurements, ultimately generating personalized human models for garment customization. This algorithm proves effective for cases with minimal contour variations where the contour closely matches its convex hull, though further refinement is needed for contours with significant variations (e.g., female bust contours). Reference [5] develops a size-driven human model using free-form deformation techniques. The algorithm optimizes conventional free-form deformation methods by classifying control points in the Discrete Forward Function Derivative (DFFD) and applying them to create models driven by critical garment-related dimensions like height and bust measurements. Reference [6] proposes a personalized human model customization algorithm employing non-uniform deformation, which integrates photographic human features into reference models through deformation algorithms to generate new, personalized and structurally optimized models. The spatial representation of cutting lines in this algorithm better captures intrinsic human features compared to conventional methods, ensuring both accurate reproduction of photographic contours and seamless model fitting without requiring subjects to assume predetermined poses. However, the shoulder joint processing requires improvement, suggesting future research should incorporate animation modeling techniques. Reference [7] also features a multi-factor-driven personalized human modeling approach developed by Geng Yulei et al. This method is based on the contour loop algorithm and proposes deformation algorithms for human models driven by size, posture, and local body shape, complemented by interactive feature surface operations to refine human features. While contour loops ensure accurate contour length adjustments, they fail to conform to natural human modeling principles. Interactive feature surface operations, however, alter contour lengths, compromising precision requirements. Reference [8] presents a semantic-driven personalized modeling approach: measuring skeletal joint positions to obtain height, leg length, and shoulder height semantic values, then performing PCA dimensionality reduction to establish semantic-value-to-model-matrix mapping. By adjusting relevant semantic values to determine PCA weights and re-mapping these weights to the model matrix, the transformed model is generated. This method, however, requires upright models for deformation, limiting its applicability. Reference [9] introduces a "block optimization" method—— for generating personalized human models using limited body dimensions. Through linear correlation analysis of parameters from standard model databases, the algorithm establishes dimensional relationships and performs fine-tuning based on input measurements. Compared to other methods, this approach produces more accurate models meeting industrial standards, though currently limited to standard postures with near-standard standing postures. Future plans include generating models with diverse postures and body types.

The literature [10] proposes a personalized modeling method based on template matching. This approach stores all parameterized human models in a digital human database. When given a set of characteristic dimensions, the system employs an iterative optimization algorithm to match specific human data from the database, identifying the most suitable model for the target measurements. However, as this method relies on holistic alignment between individual body measurements and database parameters, it cannot achieve precise matching for specific dimensions like waist circumference within the digital model library.

Reference [11] presents a personalized human body modeling method based on orthogonal single-view photographs, which reconstructs detailed geometric features of the human model by extracting limited-dimensional features from orthogonal view images. The algorithm proposes a hierarchical shape representation method to describe human geometric morphological characteristics. It predicts clients' cross-sectional 3D shapes using dimensionally extracted features from customer photos, then reconstructs their shape representations through these predictions. The generated models exhibit dimensions with accuracy comparable to scans. Reference [12] also introduces a virtual human body modeling technology for the garment industry using two orthogonal human images. This algorithm automatically extracts feature points according to human morphology rules, then deforms standard human mesh models by applying reference contours and target contours to create personalized human models. Compared with other personalized modeling methods, this algorithm demonstrates improved speed, better continuity, and local deformation performance. However, its limitation lies in significant shape approximation errors, which could be addressed through adding specific view silhouettes or employing intelligent algorithms in future research.

The literature [13] proposes a personalized modeling method based on wireframe-assisted deep learning. This approach utilizes hierarchical human statistical learning through deep neural networks (DNN), decomposing the entire problem into smaller, more manageable subproblems by layering feature wireframes. Feature wireframes are sets of semantically defined feature curves on the human mesh. By clustering the entire mesh surface into separate surfaces for feature interpolation, each segmented area undergoes PCA operation. DNN and linear regression are then employed to learn spatial relationships between semantic parameters, wireframes, and surface patches respectively. A practical application of semantic parameterization demonstrates the method's effectiveness by directly linking semantic parameters to feature wireframes rather than the mesh. Within this hierarchical structure, feature wireframes serve as proxies bridging semantic parameters and the mesh while retaining semantic information. The proposed method for human statistical learning using feature wireframes exhibits scalability and superior quality, outperforming previous studies in reliability, accuracy, and robustness.

3. The Shortcomings of Related Research Work

Personalized 3D human modeling enables rapid and accurate recreation of three-dimensional human models based on user-defined requirements or dimensions. However, due to the complex anatomical structure and diverse human movements, existing methods cannot guarantee robustness, modeling accuracy, or efficiency in terms of time and space complexity.

First, the model reconstruction efficiency requires improvement. As reported in reference [3], a system utilizing three Kinect depth cameras successfully reconstructed personalized human models. This algorithm demonstrates strong usability by eliminating the need for rotating platforms or other equipment, simplifying system setup, and requiring minimal user movement—making it more user-friendly. However, the method has limitations: reconstructed models lack sufficient precision, with details like facial expressions, hairstyles, and fingers often being omitted. Additionally, post-processing still demands considerable time. Achieving real-time 3D virtual human model generation would significantly expand the system's practical applications.

Secondly, the accuracy of local deformation algorithms requires improvement. The equivalent loop deformation modeling method proposed in [7] ensures accurate contour length variation, but its human body deformation patterns deviate from physiological modeling principles. The interactive operations of feature surfaces alter contour lengths, resulting in insufficient contour length precision. The personalized modeling approach based on template matching in [10] relies on holistic alignment between human feature dimensions and database parameters, yet fails to achieve precise matching for specific measurements (e.g., waist circumference) with digital model libraries. The personalized modeling technique using two orthogonal human images in [12] exhibits significant shape approximation errors. Future research could focus on addressing these issues through adding specific view silhouettes or employing intelligent algorithms.

Furthermore, the applicability of local deformation algorithms requires further improvement. The human lumbar profile deformation algorithm proposed in reference [4] is suitable for cases with minimal contour undulations where the contour closely matches its convex hull. However, this algorithm still requires refinement when dealing with significant contour variations, such as female breast contour modeling. Additionally, the semantic-driven personalized modeling method in reference [8] has limitations as it requires models in an upright position for deformation, which restricts its practical applications.

4. Future Expectations

Based on the above discussion, this research can be carried out from the aspects of improving the speed, accuracy, applicability and robustness of human personalized modeling.

First of all, the paper deeply studies and analyzes the human body's morphological changes and modeling laws, improves the accuracy of local deformation algorithm, and develops a new algorithm for dynamic simulation of human body's body shape and fat change process.

Secondly, the algorithm efficiency is optimized to shorten the post-processing time, and a personalized 3D human body model can be established dynamically in real time, so that the system has a wider application.

Thirdly, special algorithms are developed for facial expressions, hairstyles, fingers and other details by combining image processing technology and machine learning. Special local deformation algorithms are developed for areas with large contours, such as female breasts, to improve the practicality of the algorithm.

Finally, by integrating the research results of robotics, artificial intelligence, computer vision and machine learning, the personalized human model modeling algorithm is further optimized and improved to provide personalized human modeling solutions for virtual fitting, clothing engineering, film and television, games and ergonomics.

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