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Rapid 3D human body modeling based on Kinect technology

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Abstract: The 3D shape of the human body is useful for applications in fitness, games and apparel. Accurate body scanners, however, are expensive, limiting the availability of 3D body models. In this paper, we focus on the human body 3D modeling using one Kinect sensor modeling method. To get the human body model fast, three steps in rapid modeling of the human body are carried out. Firstly, according to anthropometric parameters, the standard model is parameterized; Secondly, the Kinect depth image of the human body model is gotten through, then, by using the PCL library the point cloud data is processed and matched, and the human body model is optimized; Finally, the realistic human body model is obtained with the rapid integration of the standard model and PCL library.

Key words: human body model; rapid modeling; PCL; Kinect sensor; anthropometric parameters

1. Introduction

Reconstruction of 3D human body object can be cheaper, such as photos and videos as easy to obtain, the object model can be applied to more areas, such as business website platform and online shopping website. In the 3D virtual fitting system [1-2], human body model is a representation of the geometric characteristics of the virtual environment and the behavior of the multifunction perception, and thus is one of the most important roles.

At present, there are mainly two kinds of methods to acquire a 3D human body model: (1) Using modeling software, such as Poser, Maya, 3DMax and so on; (2) Using 3D laser scanners. We can use the laser scanner to automatically obtain the reality human body surface geometry data. The human body model created by software is pleasing to the eye, but the process is very complex, tedious, and very time-consuming. The specialized 3D modeling tools can help us to improve efficiency, but it is difficult to grasp for designers without long-term training. This greatly increases the cost of products. Therefore this method is very restrictive. The second method also has a lot of limitations. Using 3D laser scanners, we can acquire some perfect models which can capture the detail on object's surfaces. Unfortunately, these equipments are usually expensive and the scanning speed is slow. Moreover the biggest difficulty is that we must deal with a series of point cloud data obtained. Therefore, the efficiency is very low. The above modeling methods cannot be applied ideally in the timeliness strong 3D virtual Try-on Environment.

The Microsoft Kinect sensor [3-5] may bring a revolutionary change. Kinect is mainly designed for human-computer real-time interaction. Kinect-based reconstruction techniques have the following advantages:

(1) The Kinect can get the depth information of the scene quickly;

(2) It is an active sensor, which is free from environmental interference of the visible spectrum;

(3) The Kinect is inexpensive. Its core equipments are a color camera, an infrared transmitter and infrared CMOS camera. These devices are relatively inexpensive.

(4) In addition, it is also easy to use, and its operations are similar to the ordinary camera.

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Therefore, it is beneficial to use the low-cost sensory equipment for developing the fast lifelike human body model, which is also a trend in modeling development. We just only used one inexpensive Kinect to get the depth image and point cloud of human body and develop fast algorithm to reconstruct the lifelike human body.

The body human model is a key part of the 3D virtual try-on environment. The speed of the human body modeling and model fidelity, are the important factors to concern. In the past research, the human body model has been the bottleneck in 3D virtual fitting system [6].

3D Fitting System [7], which provides a real-time interactive platform, allows users to choose clothes and try them on the virtual body model. In order to make the customers to choose and try on clothes conveniently, the rapid human body modeling technology is a necessary. It will show reality clothes looking on the body and give the consumers a more intuitive feel. With the development of the augment vision technology, augment reality technology [8-9] and virtual reality technology [10], the research of 3D virtual try-on environment is more and more meticulous and thorough.

However, it is facing some difficulties:

(1) In commercial application, it is difficult to promote due to the extraordinarily high prices;

(2) In technology and research, there are many challenges, such as, establishing the human body model rapidly, effecting of clothes deformation.

It is our motivations and objectives that acquires human body modeling rapidly for 3D virtual try-on environment. We use one Kinect to get the original data. In the paper, we proposed the rapid modeling method.

2. Related work

Currently, there are some works about the research on the human body modeling. Some methodologies include integrating OpenGL and 3DS technology making human body model, B-spline surface patches modeling method, messy points interpolation method, voxel decomposition method, Constructive solid geometry, polyhedral modeling and so on. The most common method is to get to the standard 3D human body model through a parametric method [11-13], where the standard model can be created using some software or 3D laser scanners. Of course, the parameters are more detailed more approximation of the realist our model. But it still lacks of an effective method for generating human body model rapidly.

In 1960's, we have seen the introduction of new scanning technologies, which revolutionized the 3D human model reconstruction. Initial scanning devices were only able to capture one side of the body at a time, until 1985 when Magnant [14], developed a system that completely surrounded the body [15].

Scanning technologies have significantly been improved in the last decades. Several companies currently manufacture 3D scanners, e.g. FaceSCAN3D [16], BodySCAN3D [17], FastScan™ [18] (Fig.1, Fig.2), among many others, each utilizing somewhat different scanning techniques, capturing a distinct number of data points and producing slightly different results. As the cost of scanning technologies begins to decline, research using 3D scanners is becoming more accessible to both universities and industry.

Fig. 1. Fast scan scorpion.

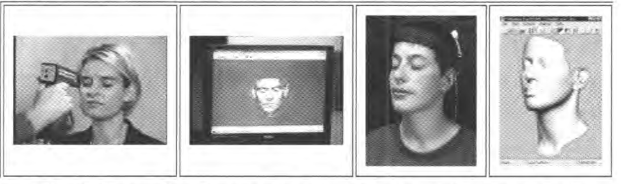

Fig. 2. Scanning human body using (FastScan™ [17]).

Now, the new trend is that, there are many universities and research institutions who are focusing on using the Microsoft Kinect sensor to get human body model. Tong Jing etc. [19], proposed a Kinect-based human reconstruction method (a slight deformation of non-rigid body) by capturing data from several Kinect sensors. Zheng Xiao etc. adopted a methodology by getting the body of the 3D gestures [20]. The open-source project of KinectFusion [21-22], which is developed by imperial college of London and Microsoft Research, it has important reference value. Cui et al. analyzed the scanning data to reconstructed body model [23-24].

As discussed above, at the present, to research on modeling algorithms for human body, requires rotating human body or scanner (Kinect) itself. Furthermore, it needs more time to ensure the adequacy of the data. These factors will affect the efficiency of the rapid modeling. Based on the above modeling techniques, we put forward a rapid modeling method for the 3D virtual fitting system.

3. Algorithms

The human body model which was obtained by using Kinect has lots of noise and no regulations. First of all, we make the object model gridded. Secondly, we should process the human body surface grid data with aligning, smoothing and de-noising. Considering the speed of processing and the optimization qualities, we use the classical ICP (iterative closest point) [25] algorithm to match with the model mesh. Then, we need to combine our model with the standard model. Taking into account the matching features, we combine the PCL library with the EM-ICP algorithm to align and reconstruct of human body model. Finally, we must do some further optimization (parameterized) to get the better qualities model.

3.1 ICP

ICP (Iterative Closest Point), is a popular and well-studied algorithm for 3D shape alignment. And it is a method that based on free-form surfaces matching. The basic ideas are as following:

(1) Initialize matching points. According to the sets of points on the original model, find the corresponding sets of points on the replication model.

(2) Find exact matching points. Firstly, we should compute the square of the distance between the corresponding points. Then, we can transform it into the form of parameters, according to the method of least squares.

3.2 The basic principles and calculation steps

There are two point sets, namely, P_L and P_R, which includes n points in 3D space R^3, as listed in Eq.1 and Eq.2.

$$P_L = \{P_{l1}, P_{l2}, \ldots, P_{ln} \mid P_{li} \in R^3\} \tag{1}$$

$$P_R = \{P_{r1}, P_{r2}, \ldots, P_{rn} \mid P_{ri} \in R^3\} \tag{2}$$

3D space point set P_L and P_R should be corresponded after P_L was transformed in three-dimensional space R^3. The purpose of the ICP algorithm is to find rotation matrix R and the transfer vector t. Through R and t, we transform P_L (fixed) to P_R, to make the collection of the smallest residual error (see [26] for a detailed study).

The mainly stages of the algorithm:

(1) Selection of some set of points in one or both meshes.

(2) Matching these points to samples in the other mesh.

(3) Weighting the corresponding pairs appropriately.

(4) Rejecting certain pairs based on looking at each pair individually or considering the entire set of pairs.

(5) Assigning an error metric based on the point pairs.

(6) Minimizing the error metric.

The algorithm of ICP has been developed and improved for several years. In this paper, we mainly use it to improve the speed of matching between scanning human body model and the standard model.

3.3 EM-ICP

EM-ICP [27] is the improvement of ICP. Their main differences: for the ICP, each point P_{li} (i =1, 2, ..., n),belonging to the point set P_L ,has only one and unique corresponding point in the set P_R. And contrary, for EM-ICP, each point in the set P_R has a corresponding relationship with P_{li}, and uses weight to represent the confidence level. Consequently, EM-ICP takes two point sets P_L and P_R, and finds R and t that minimizes the error function, as listed in Eq.3.

$$\begin{aligned} E(R,t) &= \sum_{j=1}^{n} \sum_{i=1}^{m} \alpha_{ij} d_{ij}^2 \\ d_{ij} &= \left\| P_{lj} - (RP_{ri} + t) \right\| \end{aligned} \tag{3}$$

Where α_{ij} is the probability that P_{li} matches to P_{rj} and given by Eq.4 and Eq.5.

$$\alpha_{ij} = \frac{1}{c_i} \exp\left(\frac{-d_{ij}^2}{\sigma_p^2}\right) \tag{4}$$

$$C_i = \exp\left(\frac{-d_0^2}{\sigma_p^2}\right) + \sum_{k=1}^{n+1} \exp\left(\frac{-d_{ik}^2}{\sigma_p^2}\right) \tag{5}$$

Where σ_p is a characteristic distance which decreases over ICP iterations (p stands for "points"), and C_i is computed so that the sum of each row of the correspondence matrix [α_{ij}] is 1 [27]. So, in our application, σ_p and d_0 are constants.

3.4 Depth of object processing

In this paper, we represent human body model in the form of 3D mesh. And namely, the grid shows the shape and posture of the human body. We represent by θ. $t_x(\theta)$ represents every pixel x in the overlap between the standard model silhouette S(θ) and scanning silhouette T by finding the front most triangle that projects into x. And let $U(\theta) = \{(x_1, t_{x1}(\theta)), \ldots\}$ for all x in $S(\theta) \cap T$. For each pixel we have the scanning depth D_x, and for the corresponding triangle t we find the depth, $D_{x,t}(\theta)$, along a ray through the pixel center to the plane of the triangle(here, Alexander Weiss [28]). So our depth objective is:

$$E_d(\theta; U) = \frac{1}{|U|}\sum_{(x,t)\in U} \rho(D_{x,t}(\theta) - D'_x) \qquad (6)$$

3.5 PCL

PCL (Point Cloud Library) [29], is a comprehensive free, BSD licensed, library for n-D Point Clouds and 3D geometry processing. PCL is a fully template, modern C++ library for 3D point cloud processing, which implements a large number of point cloud universal algorithm and efficient data structures, involving the point cloud acquisition, filtering, segmentation, registration, retrieval, feature extraction, recognition, tracking, surface reconstruction and visualization.

PCL can improve the real-time nature of the program. K-nearest neighbor search method is based on the FLANN (Fast Library for Approximate Nearest Neighbors). Currently, it is the fastest technology. All modules and algorithms of PCL are sent the captured data by Boost shared pointer. Thence, it avoids multiple replication already existing data in the system.

In this article, we combine PCL with Kinect to fast process point cloud data which were captured by Kinect sensor. This can improve the calculation speed greatly. So far, we gridded the point cloud data, matched point data with reference standard template, processed the depth of data, and reconstructed the human body model successfully. The next, in the part of implementation, we will do further optimization.

4. Implementation

4.1 Parametric design

In order to optimization of the process of the human model, we cited 10 measured parameters [30-32] that determines the shape of the human body model. The ten parameters include: Stature, Leg Length, Arm Length, Neck Girth, Chest / Bust Girth, Under-bust Girth, Waist Girth, Hip Girth, Upper Leg / Thigh Girth, Lower Leg / Lower Limb Girth. Those parameters corresponding relationship with the human body model are shown in Fig.3 and Table1.

Table 1. Measured parameters.

	Body Measurement parameters
1	Stature
2	Leg Length
3	Arm Length
4	Neck Girth
5	Chest / Bust Girth
6	Under-bust Girth
7	Waist Girth
8	Hip Girth
9	Upper Leg / Thigh Girth
10	Lower Leg / Lower Limb Girth

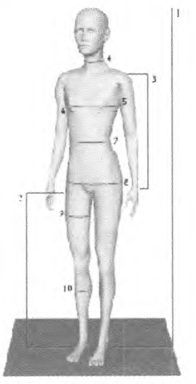

Fig. 3. Anthropometric illustration (From Ugur [32]).

4.2 Kinect depth data processing

In our experiment, the user and the one Kinect sensor need not rotate, they are fixed. So, it is very convenient for user in 3D Virtual Try-on Environment. We just only obtained half of the grid model original data (as shown in Fig.4). We just get several frames of data model of the user's data and reduce scanning time, which makes our system more intelligent. But it is difficult for us to process the data. After analyzing, we use the algorithm of depth model energy minimization. See Eq.7.

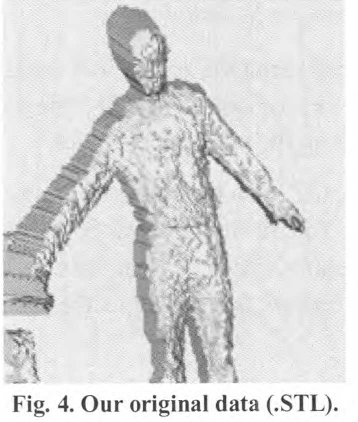

Fig. 4. Our original data (.STL).

4.3 Skeletal data

Another benefit of Kinect sensor can not only getting the user's model date, but also can access to the user's bones data easily. And we need these corresponding bones data to drive the human model in 3D virtual try-on system.

4.3.1 Skeletal Tracking

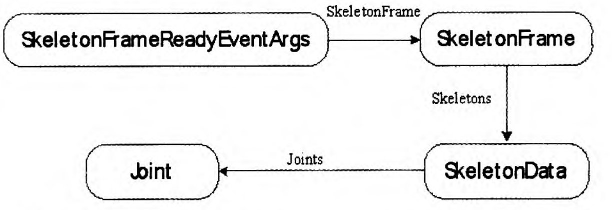

Fig. 5. Skeletal tracking implementation class diagram.

The main structure of skeletal in the Kinect SDK is shown in Fig.5.

Through the class *SkeletonFrameReadyEventArgs*, we acquire each frame of data which is stored in the structure *SkeletonFrame* which records lots of information includes: skeleton data, the current timestamp, reference plane and so on. And we just need skeleton data. The skeleton data is recorded in the class *SkeletonData* which records 20 human bones information (shown as Fig.6) and the tracked state, current position and rotation .etc. According to those information, we can determine whether the user is in the tracking range and the precision.

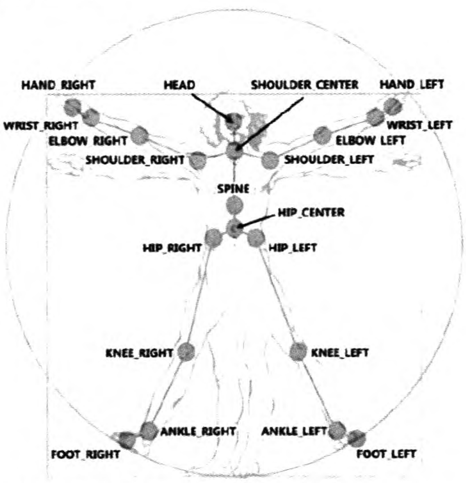

Fig. 6. Kinect SDK skeleton distribution.

4.3.2 Skeleton Blend

After we get the model skeleton data, it can control the rapid generation of real model. We just need to do simple binding. So far, there have been some of algorithms about model controlling and high precision. We utilize the classic algorithm linear blend skinning [33]. Our mesh vertex is bound to more than one bone (joint). Each vertex V_k, $k \in \{1,2,..,n\}$ is influenced by joints with indices $T_{k,1}$, $T_{k,2}, \ldots \ldots T_{k,m}$ Then we calculate the deformed position of vertex using the following formula:

$$v_{k'} = \sum_{i=1}^{m} w_{k,i} T_{k,i} v_k \tag{7}$$

Where m is the number of bones, $w_{k,i}$ are weight of V_k attachment to joint i and $\sum_{i=1}^{m} w_{k,i} = 1$. $T_{k,i}$ is the transformation matrices of the joint i.

4.4 System Framework

According to the design ideas of this paper, our system flow chart as shown in the following Fig.7 and Fig.8, in Fig.7, we divided the standard model parameters into two parts. We use L to represent the longitudinal parameters and use T to represent the transverse parameters. So L= {Stature, Leg, Arm} and T= {Neck, Chest /Bust, Under-bust, Waist, Hip Upper, Leg/Thing Lower, Leg/Lower Limb}. With updating the value of L and L, we can get the new standard model.

Through the above processing, we can get the model rapidly, which can be applied to the 3D virtual fitting system.

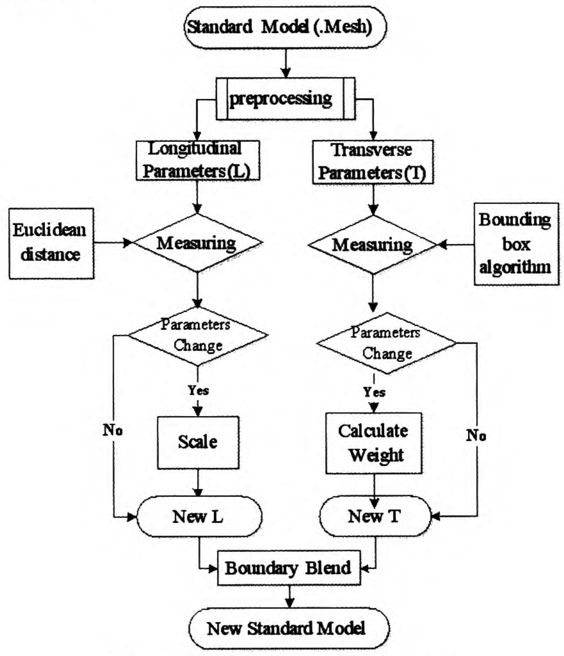

Fig. 7. Standard model processing.

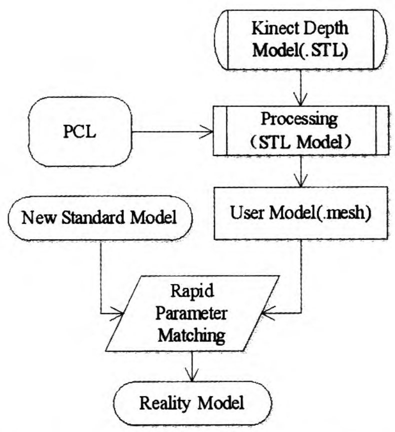

Fig. 8. Kinect depth model processing.

5. Result and Discussion

Combining the standard human body model (Fig.9 shows the reference standard model) with the scanned data for a specific user, we can quickly reconstruct the 3D mesh model of the user, as shown in the Fig.10. In the beginning, we get a sequence of point clouds. Each point cloud frame has about thirty thousand points. Considering the speed of reconstruction and the quality of the model, we just get three consecutive frames from the data sequence. We first perform denoising operation on these frames and then we triangulate them to get their topology. Then, we simplify the mesh again with the method of alignment and smoothing to get our fast user model which has about 10,000 points.

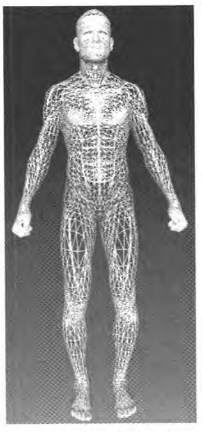

Fig. 9. Reference standard model (From poser standard library model).

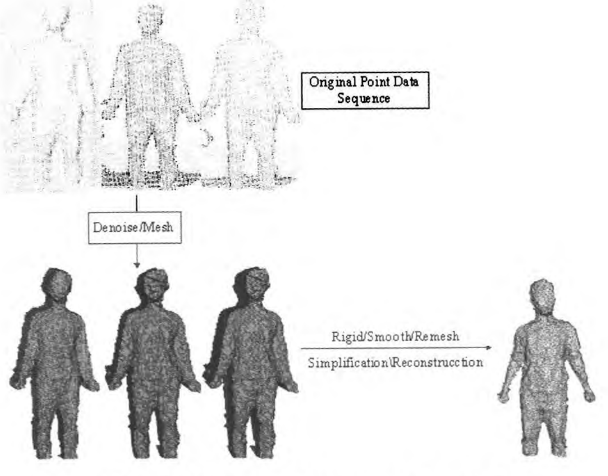

Fig. 10. Process and get our fast model.

The whole processing time for each human body is about 8 seconds under C++, the PC setting is Intel(R) Core(TM) i3-2100 CPU 3.10GHz, 4GB RAM memory, GeForce GTS 450 2G ,Windows 7 system. For the "Human standing" model, Y. Cui [21] need to capture about 30 key frames. And it speeds 278 seconds generating model. In our system, we only need to capture 3 key frames, and speed 8.73 seconds generating model. Since the models are not the same people, we just compare the number of key frames and whole processing time.

Compared with current equipment and software, we just need one Kinect which needn't to be rotated. We establish the human body model about eight seconds.

The model is good for the dressing. It is extremely simple and easy to operate for our system. Furthermore, the scanned human body needn't to rotate or move. And there is no restriction for dressing. The scanned human don't have to wear special clothes, or tight clothes. So, this method is more acceptable to customs.

6. Conclusions

In our system, user's model can also be obtained by adjusting the depth value and removing incomplete skeletal model. The model represents the user's data for dressing. Furthermore our system is not sensitive to ambient light. There are also some drawbacks in current work. Such as there are no textures on the model, and compared to standard model (Fig.9), our constructed model is still rough and not accurate. In the future work, it will be important to improve the reconstruction quality greatly.

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