Automatic Joints Extraction of Scanned Human Body

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Abstract. This paper presents an automatic method to extract joints accurately from scanned human body shape. Firstly, model is divided into slices by a group of horizontal parallel planes and primary landmarks are determinated according to the slices. Additionally, we propose a model intersection method based on direction of limbs. Model is separated into five segments including torso and four limbs and approximate direction of each segment can be calculated according to the primary landmarks. Five groups of parallel planes perpendicular to corresponding segments are employed to divide each segment into slices, and contours are calculated by intersection detection between planes and triangles. Finally, we propose a circularity function differentiation technique to extract key contours at joints from segments and the joints can be calculated according to centroids of the key contours. The experimental results demonstrate that the method has more advantages than the conventional ones, especially in algorithm's accuracy and robustness.

Keywords: Joints Extraction, Virtual Human, Scanned Human Body.

1 Introduction

Since the whole-body scanner was introduced into human body modeling, interests have been focused on automatic joints extraction from scanned human body models. With the development of three dimensional laser scanning technology, human body surface information accurately describing the human shape can be captured easily. Although the scanned human body data contain thousands of triangles and vertexes, the data have little semantic information and are difficult to be used in character animation, anthropometry and cloth simulation. For the purpose of effective use of the human body data, it is necessary to extract semantic information from the data, especially joints of the human body.

Nurre[2] presented a method to segment the human body in a standard posture (erect posture with arms and legs slightly apart) into six parts. This method divided human body into lots of horizontal slices and assigned each slice to corresponding part by analyzing the size and position of convex hulls of each slice. Ju[3] proposed an approach to extract joints from human body in the standard posture. In this approach, after horizontal slices were extracted by firing rays from the centers of the body to the surface, body was segmented into five lump parts according to the perimeter

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distributions of slices, and each part was further segmented based on curvatures of perimeter profiles of the part. Dekker[4], Buxton[5] and Ma[6] described techniques to segment human body by reentrant algorithm and to detect important joints such as shoulder, elbow, wrist, waist, hip, knee and ankle by analyzing the distributions of the slices' average radius. João[7] refined the techniques by detecting important joints according to local shape characteristics such as local maximum curvature. Werghi[1] and Xiao[9] proposed an approach to segment human body into parts by Morse theory and Reeb graph, but this approach did not extract the joints of human body which is very important for character animation and anthropometry. Lawson [11] proposed a method which discretized the model, computed its discrete medial surface, and created the skeletal structure. The method could even be applied to the animals, but it did not give an accurate result. Wang [10] proposed a method to extract joints by detecting feature lines and using the statistical anthropometric proportion. Yueqi Zhong[8] used the proportion of head length to body height as the benchmark in model segmentation and joints extraction.

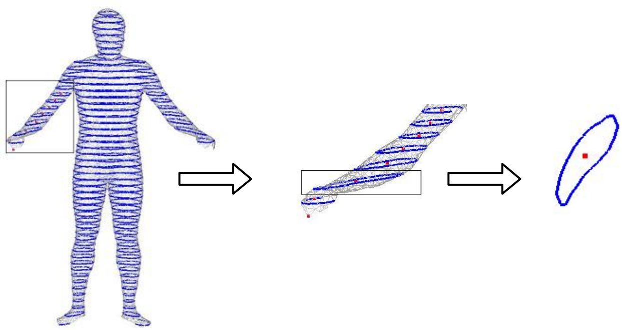


Fig. 1. Errors for intersecting with horizontal planes

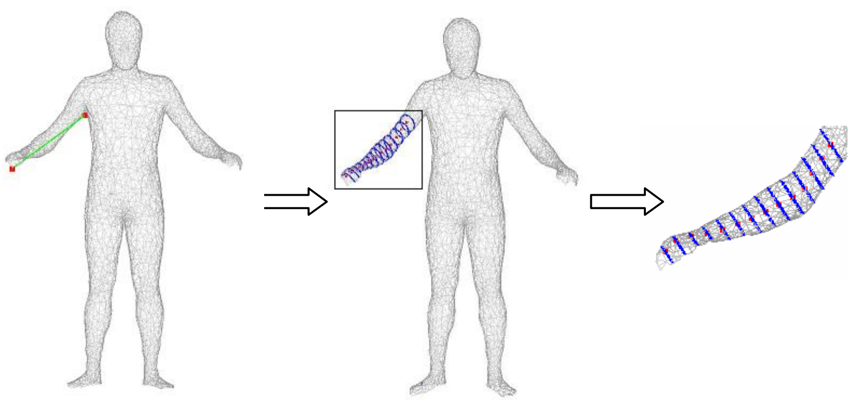


Fig. 2. Intersecting arm with parallel planes perpendicular to arm

These methods were proposed to extract joints from scanned human body automatically. But all of them have two limitations: 1) not robust. Model intersection with horizontal planes often brings errors, especially when human posture is slightly changed (Fig. 1); 2) not very accurate, because no prior anthropometric information is effectively utilized.

This paper proposes a novel joints extraction method to overcome the aforementioned limitations with three main steps. Firstly, model is divided into slices by horizontal planes to find primary landmarks[1]. Secondly, we propose a model intersection method based on direction of limbs to improve the model intersection process, so errors are eliminated when the human posture is slightly changed (Fig. 2). Finally, we propose a circularity function method to produce accurate results according to prior anthropometric assumption that the key contour near the joint is more irregular than the rest. We describe the method in the next section, and show our results and conclusions in section 3 and section 4 respectively.

2 Joints Extraction

All human bodies in this work are scanned in an erect posture with arms and legs slightly apart, and also lightly clothed, which allowed us to carry out 'touchless' measurements. The scanned human body model is represented as triangular meshes and each scanned model has about 5000 triangles and 2300 vertices (see Fig. 3).

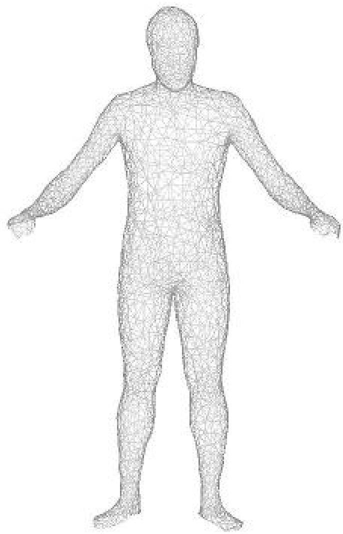
In our work, the human model is treated as an articulated layered model. We use two layers: skeleton and skin. The structure and hierarchy of the skeleton that we wish to build are shown in Fig. 4.

In this section, parallel planes perpendicular to directions of limbs and torso is utilized to divide the human body model into slices, and the circularity function method is used to evaluate the characteristic of the slices for extracting joints from model.

2.1 Model Intersection

The previous methods produced contours by intersecting model with horizontal parallel planes, and extracted joints from the model by differentiating perimeters or average radii of a group of contours. However, model intersection in these methods often produced errors, when posture of the model was slightly changed. Fig. 1 shows the errors in intersecting model that a contour in Fig.1 even covers both palm and elbow because angle between forearm and horizontal plane is less than 20 degrees. Centroid of the contour that covers both palm and elbow in Fig.1 is usually considered as a joint in the previous methods, because the contour often has extremum of perimeter or average radius among all contours. The errors in that condition will not be reduced, unless a novel model intersection method is utilized.

To overcome the difficulty, we propose a novel method to intersect models correctly. Firstly, human models are divided into a group of slices by horizontal parallel planes. Unlike the previous method, these slices are not utilized to extract joints in this method, but merely to detect the primary landmarks, such as the top of the head, left and right armpits, crotch and ends of the arms and legs, by using the previous method [4].



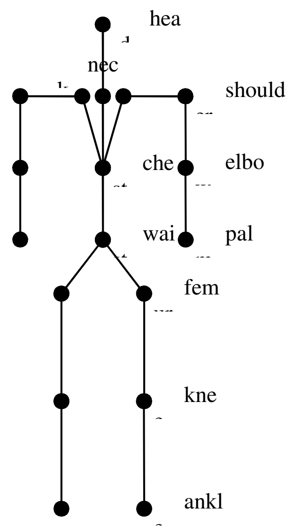


Fig. 3. Scanned human body **Fig. 4.** Structure and hierarchy of skeleton

Secondly, directions of the left arm, the right arm, the left leg, the right leg and the torso are calculated. The arms can be segmented from the torso by detecting the transition slice that indicates the branch point at the armpits. Afterwards, the direction of the arms can be determinated approximately by the armpits and the ends of the arms. Similarly the legs can be segmented from the torso by detecting the crotch and the end of the legs, and their direction can also be calculated. The direction of the torso can be determinated by detecting the crotch and the armpits.

Thus, the human body model is composed of five segments including left arm, right arm, left leg, right leg and torso. Each segment is divided into a group of contours by intersecting the segments with parallel planes perpendicular to the direction of the corresponding segment. Fig. 2 shows result of arm intersection with planes perpendicular to the direction of the arm.

2.2 Joints Extraction

During the model intersection, the contours are produced to represent the human body model. The centroid of each contour can be calculated using formula 1, and every centroid $\overline{p_i}$ is a candidate joint. Thus, the problem of finding out the joint from the centroids in transformed into finding out the key contour at the joint from all contours of the segment.

$$\overline{p_i} = \frac{1}{n}\sum_{j=1}^{n} p_{ij} \tag{1}$$

In Formula 1, n is the number of vertices in a contour, p_{ij} is the vertex j in contour i. $\overline{p_i}$ is the centroid of the contour i.

We propose a new method, namely circularity function method (CFM), to extract joints from the model. In other words, we are trying to distinguish the key contour at the true joint from the other contours.

An assumption is made for the circularity function method that the key contours at the joints are irregular because the bones and muscles clearly affect the shape of contours, on the contrary, the other contours are more regular and closer to the shape of circle because the connective tissue covers bones evenly.

The circularity function (shown in Formula 2) is utilized to estimate how close the contour is to circle.

$$g(M) = \frac{4\pi \cdot s(M)}{c^2(M)} \tag{2}$$

M is a contour of the model shape, s is the area of the contour, c is the perimeter of the contour and g is the circularity of the contour. When M is like a circle, g runs to 1. Contrarily, g runs to 0.

According to the assumption, the circularity function gains local minimum in the key contour whose centroid is a true joint because the key contour is more irregular than the others. Thus, the problem of joints extraction from scanned shape can be converted to a problem of resolving minimum of the circularity function of the contours in human body (Formula 3). In Formula 3, M_{joint} is the key contour that contains the joint.

$$M_{joint} = \arg\min(g(M)) = \arg\min\left(\frac{4\pi \cdot s(M)}{c^2(M)}\right) \tag{3}$$

Thus, the position of the joint can be calculated by Formula 4.

$$\overline{p}_{joint} = \frac{1}{n}\sum_{i=1}^{n} p_i, \qquad p_i \in M_{joint} \tag{4}$$

The circularity function curve of trunk and right leg is shown in Fig. 5. All the joints except in the shoulders and thighs can be extracted from the body model by the circularity function method, such as palms, elbows, knees, ankles, waist, chest and neck. Shoulders can be obtained from armpits, and thighs can be calculated based on waist and crotch.

3 Experimental Results

The scanned human body model in our experiment is represented as triangular meshes and each scanned model has about 5000 triangles and 2300 vertices. Twenty models are available for experiment of joints extraction, and some results are shown in Fig. 6.

Some previous methods[2][7] are implemented in this work to compare with our method.

Some parameters that can accurately reflect results of joints extraction and can be easily obtained from position of the joints are selected elaborately according to anthropometry, like length of leg, thigh, forearm and upper arm. Table 1 shows true value of the parameters and results of the previous methods and our method. Obviously, our method is more accurate and more robust than the previous methods.

Table 1. Results of the previous methods and our method

Average length (cm)	True value	Perimeter method [2]	Feature detection method [7]	Our method
Length of leg	40.6	37.4	41.3	40.5
Length of thigh	49.2	51.1	47.1	48.9
Length of forearm	25.6	22.8	25.0	25.6
Length of upper arm	31.6	32.3	32.1	31.1

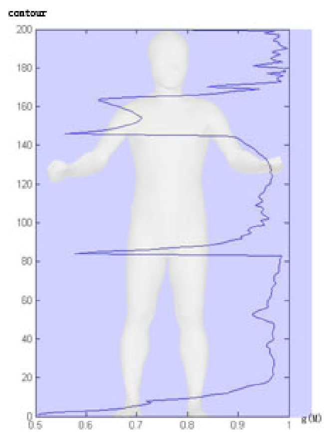


Fig. 5. Circularity function of trunk and right leg

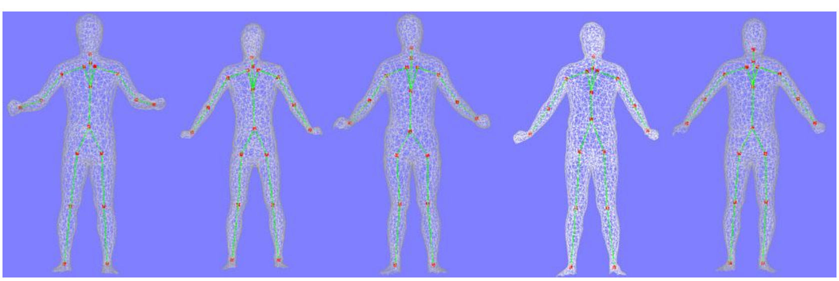


Fig. 6a. Joints and scanned human body

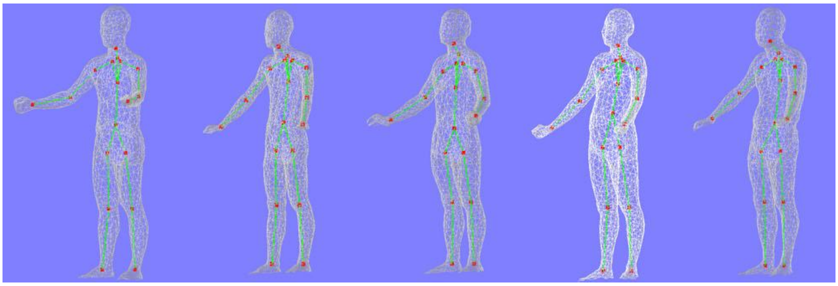


Fig. 6b. Joints and scanned human body

4 Conclusion

We have presented a novel algorithm to intersect scanned human body model and extract joints from it. This method uses a new model intersection technique and circularity function, avoiding errors by intersecting errors and improving the result of the joints extraction. Compared to the previous methods, our Algorithm has two advantages:

1) Robustness
Previous methods that intersect the model by horizontal planes can not cope with scanned human body in different postures. In this paper we overcome this problem by the new model intersection technique.
2) Accuracy
Previous methods that calculate the joints of the body by resolving minimum of the perimeter or average radius function of the contours do not make any sense in anthropometry, while this paper proposes circularity function to calculate the joints on the assumption of anthropometry. The experimental results have demonstrated the accuracy of the method.

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