ROBUST KINEMATIC SKELETON OF HUMAN 3D MODEL IN VIEWING STRAIGHT LIMBS

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ABSTRACT: In 3D character animation, the creation of the skeleton is still long-winded task and relies on various manual modifications. In this paper, a novel approach is proposed to generate a kinematic skeleton for 3D human geometric model. More specifically, our concentration to create the plausible skeleton, which locates the precise position of the knee and elbow joints of the models that possessing straight limbs. Since inaccurate identification of the joints in skeleton extraction effected the quality of the character animation. Firstly, in the proposed approach, approximate locations of joints in the static model are captured. The Laplacian-based mesh contraction method with global positional constraints has been applied to obtain the skeletal shape of the model. Secondly, the correspondence relations between the joints and contracted mesh are established through K-nearest neighbors. Finally, some experiments have been performed to generate plausible kinematic skeletons on different 3D models. In addition, the correctness of the generated skeleton has been assessed by animating the skeleton. The animation of the obtained skeleton carried out through joint mapping by using 3D motion. The resulting skeletons could find its applications in 3D shape corresponding, shape interpolation mesh skinning, character animation and mesh editing.

Keywords: Mesh contraction, Kinematic skeleton, Character animation, Motion retargeting.

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INTRODUCTION

Rapid improvements in 3D geometric models plays pivotal role in pursuit of realism for 3D shape analysis and interactive computer graphics. Recently, 3D models utilize significantly in several fields, including virtual reality and scientific visualization, computer aided design (CAD) industries, simulations, preserving culture heritage, and especially in computer games and animation. The 3D human character animation has required realistic creation of animation in animated movies, surveillance systems, computer games and avatar animations. This becomes popular and thought-provoking task in graphics and forensic animation. Generally, the animation of human 3D characters is found in the articulated shape of the model, represented as a skeleton.

To identify, the exact location of skeleton joints is a well study problem in computer animation. A curve-skeleton is 1D abstract representation of the model, which helped for understanding the essential shape and topology of the 3D object demonstrates by (Le, B. and Deng, Z., 2014, Siddiqi, K. et. al., 2008 and Katz, et. al., 2003). The skeletal shape of the 3D objects has helpful for describing model and find a broad range of utilization in shape analysis discussed (Lidayová et. al., 2016 and Xuetao, Li. et. al., 2001), surface reconstruction by (Tagliasacchi *et al*.(2009), skeleton embedding reported by Baran and Popović (2007), 3D character animation explained by *(Jituo and Guodong 2011)*, object matching and shape retrieval discussed by (Cornea et. al., 2005) and shape deformation using skeleton illustrated by (Kin-Chung et. al., 2010 and Yan et. al.,2008). Due to skeleton importance and its applications, several techniques have been introduced to extract skeleton from 3D object. Several techniques have been proposed for extracting skeletons from 3D models.

However, majority curve-skeleton extraction methods described only the abstract shape of the input model which explained in (Dey et. al., 2006). In the literature, some of techniques determined to calculate a joint based of skeleton of the human model described (Jiang et. al., 2013 and Oscar Kin-Chung et. al., 2008). The various unwanted redundant joints are generated, which did not match the plausible position of the joints in the input model by using these methods. These extracted skeletons usually required a manual tweaking to delete undesirable branches. Especially, the extraction of skeleton of model consisting straight limbs, the identification of knee and elbow joints was often unsatisfactory.

In articulated shapes, joints position can be distinguished through geometric conditions like, calculating ending angels between identifying different parts, thickness and thinness region and different estimates are being used to identify the position of joints. Technically, an extracted skeleton of 3D model is well focused, well defined and well centered position of joints.

An automatic extraction of skeleton from articulated models proposed by (Jaehwan, and Sunghee, 2014). In their proposed method, the skeleton splits into two parts, topological joints and geometric joints independently. The computation cost of joints may increase due to handle the joints separately in one model. However, in their work, the shapes of the extracted articulated skeletons are star like skeleton dissimilar to the standard skeleton.

Although, different commercial 3D modeling and animation packages (Maya, Blender) have been developed for animating characters. However, in extracting of skeleton are disjointed in majority of these softwares. Usually these softwares depends on the user expertise as well as labor-intensive and time-consuming process in generation of skeleton.

In literature, majority of skeleton generation techniques for 3D human models provides room to generate an efficient solution for skeleton extraction. To address these issues, we proposed an effective and efficient approach to generate robust and kinematic skeleton for 3D human models. In proposed solution, the position of joints from the surface of the model captured visually. The visual clues on the surface of the input model can be used to create the skeleton of the model. The mesh contraction based on Laplacian method with global positional constraints has been utilized to extract the thin shape of the input shape. During mesh contraction the connectivity between mesh vertices and original topology has preserved. The corresponding of the contracted mesh and captured points are calculated. The corresponding relationship and shared vertices of the contracted shape have been used to establish the connection between adjacent nodes. The 1-ring of closest mesh vertices to the captured points has been constructed through the nearest neighboring algorithm. The resulting skeleton has been obtained by using the corresponding and connection between adjacent nodes.

The primary goal of our approach is to create a suitable kinematic skeleton of the human model, which follows the similar bones structure of the human skeleton. The adequate identification of joint position in resulting skeleton could be sufficient for realistic character animation. In proposed approach, the accuracy of the resulting skeleton has been verified by retargeting 3D motion of human joints through joint-mapping method. The segmented parts can reveal valuable properties of the 3D model which useful for further analysis and processing such as collision detection and mesh modification.

MATERIALS AND METHODS

There are many techniques have been introduced on extraction of skeleton from 2D and 3D objects. Only core and closely related techniques to proposed work discussed. **Skeletonization:** In literate there are mainly two types of methods has been discussed for extracting a skeleton, Volumetric and Geometric methods. Extraction of skeleton through geometric methods which exploit the geometric features of the given mesh or point cloud data of the model. Voronoi diagram is a popular approach in geometric extraction for calculating the skeleton from mesh vertices. Currently, (Lidayová et. al., 2016) introduced a fast-vascular skeleton extraction from vascular tree segmentation for clinical use. The working of existing curve skeleton extracting approaches for from the 3D models were well reviewed by (Cornea *et al*. 2007). Medial geodesic function (MGF) based on Voronoi diagram used for extracting a skeleton proposed by (Dey et. al., 2006; Sobiecki et. al., 2014 and Amenta et. al., 2001). Geometric methods needed pruning and thinning algorithms obtaining a skeleton due to medial surface, rather than medial axis. (Berretti et. al., 2006) proposed Reeb-graph-based methods which gained attention to compute the skeleton from mesh models. Most Reeb-graph methods required defining the explicit boundary conditions by the user.

Volumetric methods require a voxelized representation of the input model. Criteria for extraction of the curve and surface skeleton for voxel shapes was explained by (Sobiecki et. al., 2014).

(Wang et. al. 2008) proposed a method for computing smooth curve-skeleton of mesh by using iterative least squares optimization. An automatic generation of control skeleton based on Euclidean distance map (EDM) and medial surface of the voxel model presented by (*Wade and Parent.2002)* Volumetric methods are not always robust to all shapes due to additional processing for surface conversion of the model.).

However, volumetric methods may not furnish the guarantee of skeleton smoothness. Specifically, the extracted skeleton through volumetric methods is smaller than the original topology of the object. Recently, *(*Cai *et.al.,* 2017*)* introduced a gradient vector of the articulated shapes which depends on topology and flux of the model. Example-based skeleton extraction (poses-based) of the model was described by (Le, B. and Deng, Z., 2014).

Joint-Based Skeletonization: A Geometric mesh of the human shape has input to extract a curve shape of model. The triangular human mesh mode $M = (V, E, F)$

where $V=[v_1^T, v_2^T, v_3^T]$, are the vertices set of $v_i=[x_i, y_i, z_i]^T$ are the position of the v_i in 3D space. E denotes the edges and F represent the face. Initially, M contract into M' having contracted set of vertices V'. The correspondence between interactive points and contracted mesh vertices has been established. The edges of the skeleton (B) are calculated through inheriting neighbors of the mesh vertices through corresponding. The extracted skeleton $S=(U,B)$ consists the joint U and branches B detailed described in experimental section.

Mesh Contraction: In proposed work, we contracted the mesh through geometric contraction to preserve the original shape of model. The thin shape (zero-volume) obtained through contracting the surface of the model by applying geometric contraction. Generally, in geometric contraction implicit Laplacian-based smoothing with contraction and attraction constraints. These constraints are applied to maintain the geometric structure of the input model and also preserved the original connectivity between mesh vertices. The new vertices (V') of input mesh M is calculated by iteratively solving the linear system which are described in (1).

$$\begin{bmatrix} W_L L \\ W_H \end{bmatrix} V' = \begin{bmatrix} 0 \\ W_H V \end{bmatrix} \quad (1)$$

Here W_L and W_H represent the diagonal weighted matrices which are applied to balance contraction and attraction constraints. To obtain the thin shape of the mesh required several iterations with proper weights. To optimize the contraction process, after each iteration the constraints weights automatically updated.

The contracted shape of the input mesh achieved by using method of (*Au et. al., 2010*). The satisfactory curve-skeleton of the contracted mesh through Laplacian based contraction as shows in Figure 1. In their work, they have achieved curve-skeleton by implementing mesh simplification procedures, connectivity surgery process, edges-collapse operation and embedding refinements. Although, they have generated joint-based skeleton, but the resulting skeleton created unwanted joints, location of joints does not match with the original joint's location and various refinements are being used during the extraction process. The Laplacian contraction method does not ensure the centeredness skeleton the model.

The plausible skeleton of the mesh model is consisted on number of joints, connected bones, mesh surface and extracted skeleton corresponding and hierarchical relationship of joints. Particularly, the precise position of skeleton joints which followed the pose of the input model is an essential part in realistic character animation. The contracted shape (M') signify the 1D representation of mesh.

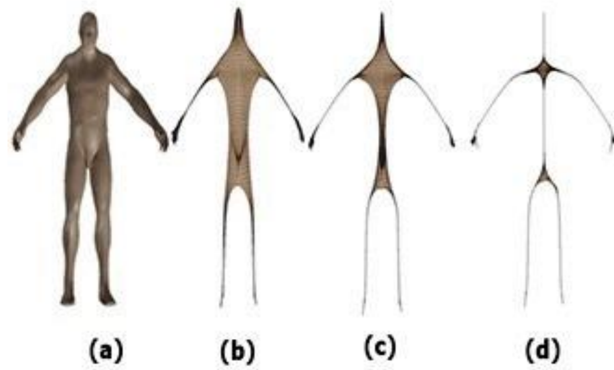


Figure-1: Mesh contraction after 1, 2, 4 and 6 iterations.

Building Node connectivity*:* The correspondence between visual clues marked by the user on the surface of the model and contracted mesh has been computed. The matrix D used to cluster the closest mesh vertices in one group based on the distance of the mesh vertices to each node on the surface of the given model. Latter, interaction points represent the joints of the skeleton. Suppose contracted mesh *is* M' and skeleton nodes (visual clues) is C. The distance D is computed as:

$$D_{ij} = \| M_i' C_j \| \quad (2)$$

Where $i = 1.2.......m$ and $j = 1.2.......n$

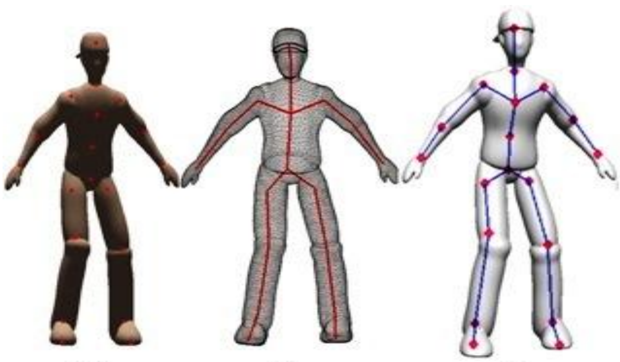
$$\| M_i' C_j \| = \sqrt{(M_{i1}' - C_{j1})^2 + (M_{i2}' - C_{j2})^2 + (M_{i3}' - C_{j3})^2} \quad (3)$$

The closest vertex $E_i = D_{I_i} i$ to node is identified through matrix D where I_i denotes the minimum distance of each node from its associated vertex of shape. Supposed that the points on the surface of the mesh are C, so their corresponding part is C too. The connectivity between the adjacent nodes is calculated through corresponding matrix.

One-ring of the closest vertices is used to establish the skeleton structure of shape through correspondence. Nearest neighbor search (NNS) algorithm has applied to computes the one-ring of mesh vertices. In computational geometry there are various solutions have been proposed for NNS problems. In proposed approach K-d tree data structure (space-partitioning NNS algorithm) has used which was introduced by (Yianilos, 1993). The NNS algorithm based on K-d tree which was iteratively divided the search space into two regions. K nearest neighbors $N_k(V_i)$ is one-ring of mesh points which is an approximate neighborhood of vertices V_i. The calculated nearest neighbors are estimated on a tangent plane expressed by their principal components analysis(PCA).

The size of nearest neighbors $k = 0.012$ which is used to define the neighbors. The upper and lower values of neighbors was bounded in [8:30]. Two adjacent nodes connected through inherit-neighboring in the rings of the shared mesh vertices.

In skeleton generation the each node of $s_i \in S$ represent the associated vertices of contracted M_i' and M which are closest each other, that is $M' = \bigcup_i M_i'$ and $M_i' \bigcap_i M_j' = \phi, \forall i \neq j$ The adjacent nodes s_i and s_j of the skeleton are linked if their associated vertices contain 1-ring of common vertices of contracted mesh. The graph of the skeleton edges was obtained through cyclic matrix of the vertices. In connection matrix, the values assigned one in case of connected s_i and s_j otherwise zero value. The user-defined points, skeleton graph and joint-based skeleton of the model as depicted in Figure 2 (a), (b) and (c) respectively.



(a) (b) (c)

Figure -2: Joint-based skeleton of the model (a) with eighteen marked point on the surface of the model presented in (c).

RESULTS AND DISCUSSION

The experimental consequent of a generation of kinematic skeleton for different 3D human models is described in this section. Dataset of the 3D human models which was proposed by (Shilane, P. et. al., 2004) was used to test the proposed approach. The total number of mesh vertices, faces and iteration for mesh contraction presented in Table 1. The result of a joint-base skeletons for different 3D human model having straight limbs as well as articulated shape of the model by implementing the proposed solution presented in Figure 3. In the first row of the figure five models with different postures its plausible skeletons along corresponding mesh model presented in the second row and third row. The resulting skeleton satisfied the relevant properties of the skeleton (centeredness, robustness and homotopic) which has described (Cornea et. al., 2007). The generated skeletons do not need any tweaking, topological thinning, connectivity operations, edge-collapse process and geometric refinements.

Table-1: Statistics of 3D human models which were used in experiments

Models	Mesh vertices	Mesh faces	Mesh Contraction Iteration	Skeleton Nodes
A	13146	26256	5	18
B	5614	11224	4	18
C	5075	10146	6	20
D	4450	8896	4	21
E	13336	26668	6	19

Comparison: Unfortunately, in many situations, the automatic skeleton extraction methods generated unsatisfactory skeleton, which does not detect the suitable position of the joint for straight limbs models. The robust generation of the kinematic skeleton for articulated and straight limbs shape of the model a certain user intervention is required which described (Ma et. al., 2014). The results of the proposed algorithm compared with previous skeleton extraction methods in order to corroborate the accuracy of skeleton generation.

To the best of our knowledge, majority of skeleton extraction studies mainly focused only on articulated shape. Because in articulated pose of the model, the identification of the joint location is comparatively easy than the model possessing straight limbs. The visual comparison of human model skeleton generation by implementing a proposed approach and four existing approaches as expressed in Figure 4. The redundant joints and bones and inaccurately position of the skeleton, joints in previous methods which are highlighted by the red arrows demonstrate in Fig-4. The resulting skeletons demonstrated in Fig-4 (e) through proposed technique soundly better perform than other methods.

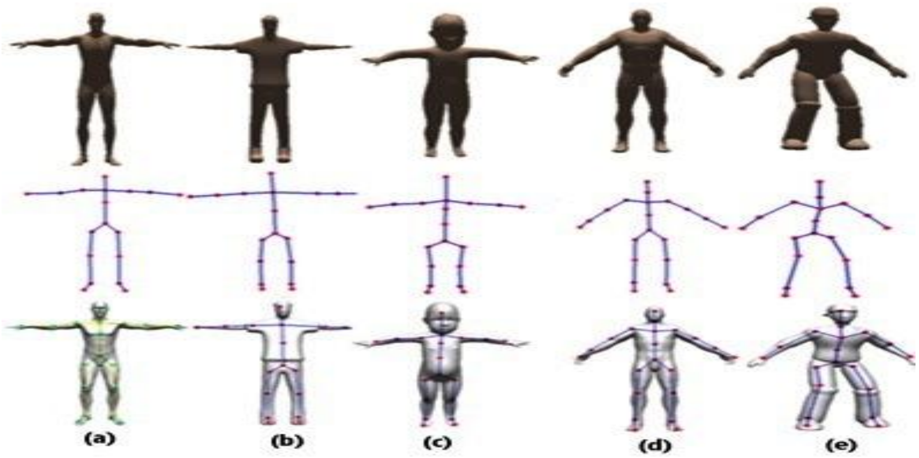


Figure-3: A gallery of joint-skeleton for different models.

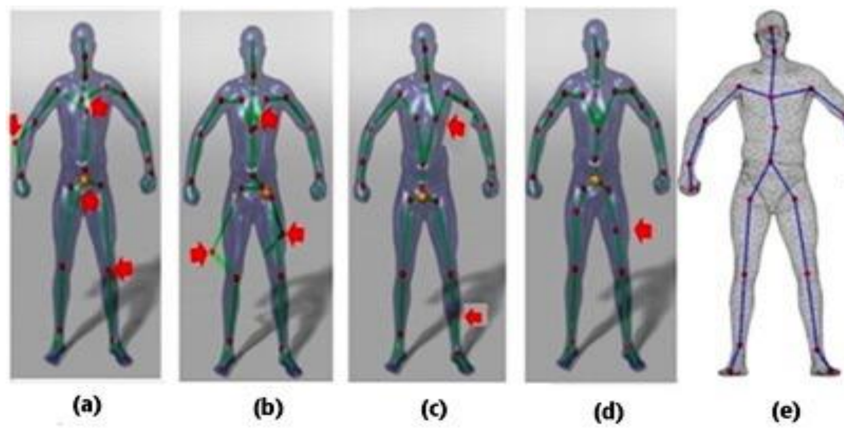


Figure-4: Comparison results of proposed methods with (Hasler *et al*., 2010; Schaefer and Yuksel, 2007; De-Aguir, *et al*., 2008; Le and Deng, 2014) methods are presented from (a-d) and results of the purposed approach presented in (e).

Application: In addition, accuracy of resulting skeleton was verified through the retargeting 3D motion of human joints to generate skeleton. The motion retargeting is the procedure to transfer captured motion of joints to the static extracted mesh skeleton. A mapping strategy of joints has been adopted to retarget motion into resulting skeleton (target). In joint mapping process the correspondence between the motion skeleton to resulting skeleton was preserved. Source and target skeletons have different number of joints.

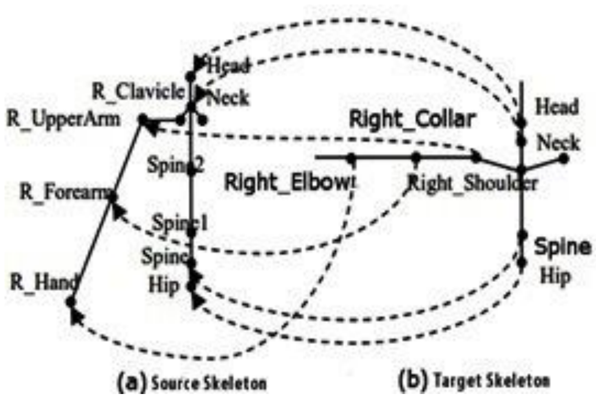


Figure-5: Joint-to-Joint correspondence between (a) and its animation sequences in (b)

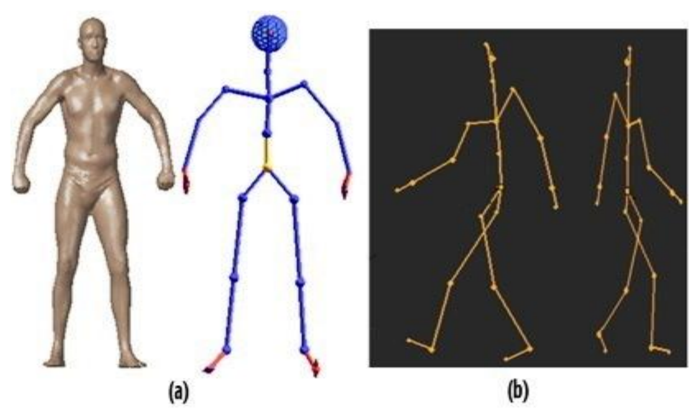


Figure-6: Kinematic Skeleton of the human model the source skeleton (motion) to target skeleton (mesh) skeleton

for one-to-one mapping of joints in both skeletons correspondence method which purposed by (Monzani, J. et. al., 2000). The mapping of resulting to motion skeleton has illustrated in Figure 5. The mapping of joints between the source skeleton to target skeleton has illustrated in Figure. 5. Animation of resulting skeleton has assessed by retargeting, a joint captured 3D motion of CMU. Although, resulted(target) skeleton comprised less number of joints also different in heights as compared to the source skeleton. The satisfactory steps of animation by retargeting motion illustrated in Figure 6(b).

Conclusion: A practical Laplacian–based mesh contraction approach has presented for generating of a plausible kinematic skeleton of the human 3D models possessing straight limbs. The proposed study demonstrated the better ways of utilized of the initial user-defined points on the surface of mesh to construct the joint-based skeleton. The proposed method has the flexibility to insert, eliminate joints and adjust joint position. In proposed approach joints identification does not required any junction detection in 3D human model.

Furthermore, the resulting skeleton could be incorporated in popular commercial 3D animation softwares for character animation.

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