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The skinning in character animation: A survey

Yanan Yang

Nanjing University of the Arts, Nanjing, Jiangsu, China
1426859187@qq.com

Abstract: *The skinning in the character animation is always one of the vital research contents in computer animation. In recent years, with the rapid development of the 3D game, animation, and film special effects production industry, the requirements for character skin technology have gradually increased, and the innovative development of skin technology has also received more and more attention from researchers, resulting in the birth of many new methods and technologies. This article focuses on analyzing different methods of skinning technology, which can be roughly divided into four categories: Direct Skinning Methods, Automatic Skinning, Example-based Shape Deformation, and Direct Delta Skinning. The contents and details of each method are listed, and the advantages and disadvantages of the above methods are compared and analyzed. Finally, aiming at the shortcomings in the current work, some problems that can be further studied are proposed.*

Keywords: *skinning; character animation; weight; Deformation*

1. Introduction

In recent years, with the continuous development of computer animation technology, advertising, and film special effects production, 3D games show a booming trend, becoming one of the most dazzling industries in the 21st century. Human animation is the leading research direction that has attracted extensive attention from researchers. One of the research points is the skin technology of character animation, one of the most active fields in computer animation research in recent years.

The landscape skinning algorithm has been divided into two major components: variational and direct methods. Variational approach: The variational approach minimizes an objective function (deformation energy) by treating the task as an optimization problem. Direct approach: Fast, suitable for interactive real-time applications and CPU implementations.

At present, there is some kind of literature summarizing the application fields and methods of skin technology at home and abroad. In this paper, we will examine the advantages and disadvantages of various skin technologies and the outcomes of their application in three categories: Direct Skinning, Automatic Skinning, and Case-based Skinning. The new work of each method in recent years and the introduction and comparison of different skin methods are introduced.

2. Direct Skinning Methods

2.1. Linear blend skinning

Linear blend skinning is the most basic and well-known direct skeleton deformation algorithm. Some of the first research ideas appear in the works of Magnenat-Thalmann [59], Badler and Morris [5]. In addition, a paper by Lewis [54] is the first to give a detailed mathematical description of linear blend skinning.

As the number of polygon calculations increased, linear hybrid skins quickly replaced rigid ones, allowing smooth transitions between individual transformations. In addition, some problems occur when transformations with different rotation components have to be mixed, when the rotation of a linear combination are no longer rotations [1]. When the mix rotates, there is considerable deformation in the wrist, elbow, and other joint parts. This situation is called 'candy-wrapper artifact.' In addition, linear hybrid skin has only a limited number of parameters. The use of more transformations is one way to extend the great ability of linear blending skinning whitening. It is usually calculated by a non-linear process of transformation from the original skeleton [46], [67], [91].

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2.2. Multi-linear skinning methods

It turns out that changing weights will not fix the 'candy-wrapper artifact' problem of linear mixing, but at some points introducing more weights will make a difference. The pose's shape and the properties of the assumed skin weight do not change during the animation, implying that the most general linear skinning model is a simple linear function. Classical linear hybrid skinning is a special form of general linear skinning, but the problem is that they are heavier and more complex in design.

Animation Space is another linear skinning model [65]. Animation space uses only four weights per vertex-bone pair, which may seem less powerful than MWE, but in fact, animation space reinforces the invariance of world space rotation. Animation Space weights, like multi-weight enveloping, are learned from examples and can suppress candy-wrapper artifacts.

The application of clustering principal component analysis to animation sequences, can also be seen as a more open linear skinning approach [76]. The basic idea behind clustering (local) analysis is to divide the input grid into disjoint parts, each of which is subjected to classical (global) principal component analysis [2]. Linear techniques that allow overlap between individual components are closer to skinning, e.g., SPLOCs models [69].

2.3. Nonlinear skinning methods

Linear skinning methods are used as building blocks in more complex algorithms because of their efficient implementation and easy-to-understand mathematical properties. For example, physics-based simulations [23]. Even so, some model shrinkage still exists during use. In addition, the idea of rotating linear mixing and replacing linear mixing with manifold intrinsic mean leads to the nonlinear skinning method, which is the most fundamental problem.

2.4. Skinning transformations

A linear mixture of translations is justified because translations form linear Spaces rather than curved manifolds. When this method is performed, we find that even the perfect internally rotated blending [15] results in much worse results than the linear blending skinning. It is also possible to design a more appropriate center of rotation, for example, a center of rotation consistent with articulation [30] and to use least-squares optimization calculations [44]. However, in some cases, each strategy may lead to artifacts [45].

Spiral motion is closely related to dual quaternion in theoretical kinematics. In fact, the actual implementation of dual quaternion skates is relatively simple.

2.5. Dual quaternion skinning

Although dual quaternion skinning can eliminate candy-wrapper artifacts, it still has many limitations. First, the unit dual quaternion linear blending (DLB) operation is performed on the unit dual quaternion linear blending (DLB), but the resulting intrinsic average of manifolds is not perfect. In addition, the application of lie algebraic averaging [26] can achieve complete intrinsic mixing, which is a universalization of spherical averaging. [45] (Algorithm DIB) discusses the lie-algebraic average of dual quaternion versions. In contrast, the difference between DLB and DIB in shortest path interpolation and skinning application is not obvious. To circumvent this limitation, the skinning process is divided into two steps. First, the rest position (including the bone) is adjusted. Second, dual quaternions skinning is used to form the desired posture (clarity). Although similar methods have been successfully applied to production scenarios (e.g., Disney's Frozen [52]), the optimal mixing of affine transformations in general has not been solved. Alexa [1] made an early investigation of this problem and proposed linear blending of matrix logarithms.

2.6. Lie-algebraic averaging

Despite the fact that Alexa's approach has been used, its non-shortest paths have some chance of leading to artifacts, e.g. [45]. In addition, remllard and paul [75] proposed an improved method of hybrid affine transformation, but this method has not been tested on the skin. Differential mixing is based on the limitations of linear and biquaternion methods proposed by [72].

The second issue with double quaternion hides is known as 'bulging artifact.' [48], [43]. When modeling, the curved parts of the character model produce some unnatural bulging effects. Note that such inflated artifacts are always not needed. To solve this problem, Kavan and Sorkine [43] proposed that the pendulum twister, based on the same observation (showing that linear mixing works well in bending), linear and biquaternion mixing are combined in a nonlinear manner.

2.7. Deformation primitives

'Deformation primitive' refers to the basic structure of deformation. The most common deformation primitive is affine transformation, but other possibilities have some benefits (for example, [42], [34], [81]). Forstmann and colleagues introduced spline-based deformers [25], [24]. Gregory and Weston [27] proposed an improved version known as offset Curve deformation (OCD). Experiments show that OCD is equivalent to animation space, and one of the advantages of OCD is that users can easily adjust its parameters.

Endpoint weight [35] is ideal for bone stretching and twisting, for example, with procedural or cartoonish characters that can be run with additional weight functions. In addition, Kavan and Sorkine (2012) proposed a broad idea of joint-based deformation (similar to linear blend skinning) for deformations in the vicinity of bone joints. The concept is simply to simplify the transition between individual shapeshifters and avoid "candy-wrapper artifact."

3. Automatic Skinning via Constrained Energy Optimization

The type of process defined for traditional character skinning is labor intensive. This process can be divided into three main steps. First, a control structure must be established around or within the character. Second, skinning weights will be drawn for each bone. Finally, the animator changes each handle to apply a transform to set the character's posture.

In fact, pipes are not always continuous. Moving to a new position often exposes weight issues and often requires constant adjustments that control structural construction. The ideal pose of the character will require more freedom to assist or change the rotation center of the joint to improve it. These automation programs provide easy operations for animators and quick prototyping methods for artists. Moreover, automation can fully automate program animation without the need for manual labor, such as audience simulation (e.g. [74]), and physics-based simulation is feasible ([23]).

3.1. Automatic skeletons and cages

Many animals and humans rely on their internal skeleton for locomotion, the arrangement of the biological skeleton is similar to its appearance, and the influence of subcutaneous muscles (e.g., biceps flexion) [69]and internal pressure (e.g., chest aspiration [88]) Should be taken seriously. In simple terms, the above effects are treated as secondary, and Skeletons' history almost the same age as computer animation are (such as [59]). And also, traditional animation textbooks ask draw the skeleton of the character before determining the pose.

In the automatic skeleton construction, we can divide the process into two parts: determining the skeleton topology and skeleton embedding. The problem with skeleton topology is how many bones are made and joined together. The problem with skeletal embeddings is the placement of bones in space or the position of the bone joint in shape. In addition, skinning can be generalized to other handle types besides skeleton.

3.1.1. Skeleton extraction

The skeleton will capture the topological and geometric characteristics of the character shape, and the flow-based approach and the segment-based approach are the two main directions of modern automatic skeleton extraction. One flow-based approach utilizes the convergence of surface flow on the internal curve skeleton. The prototype method [4] means curvature minimizes the surface area. However, the modified mean curvature flow does not guarantee shape retention at all times. Despite the fact that this is required to define the exoskeleton, modern extensions of the method merges on the central axis. [85]. In addition, various methods of stream-based skeleton extraction have emerged, such as point clouds [32], [16]. Wang and Lee [2008] proposed a flow that is superficially similar to [4]. In any case, skin 'rigid skeleton extraction' and 'curve skeleton extraction' have a fundamental difference. Curved skeletons, although superficially similar to animated skeletons, are represented by abstract, compact shapes, so they require additional rigid skeletons of straight segments or switch to non-standard skin

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squares adapted to curved skeletons [24], [25], [35], [72], [98].

The segmentation-based approach is to look for the internal skeleton. A line segment based on a heuristic input shape was proposed by Katz and Tal for finding cuts near 'deep concave' line segments, where bone joints are placed at the centroid of the cutting ring and linked to the straight-line segment to form a tree [2003]. These two points will mainly affect the quality of the segmentation-based method, and there is an ideal optimization problem. In this problem, the rigid motion caused by its basic skeleton will measure the quality of its method [33]. In contrast to the shape segmentation goal, which employs abstractions to extract a great understanding of one or a group of shapes (e.g., [89], [47]).

3.1.2. Embedding an existing skeleton

When no basic knowledge about the was in is available, automatic skeleton extraction is used; in other cases, topology and other vague geometric information can be quickly confirmed by embedding the skeleton into the shape using an automatic method (such as [38], [66]). In this case, Baran & Popovic [6] asked two questions and gave nine metrics.

Typically, we classify bone embedding problems as discomfort problems, either by making many assumptions about techniques for computer vision, such as [80] or by seeking help with disambiguation solutions. This situation arises from bone animated film inputs with in case of [38]. From a fully automated point of view, it is far from ideal for a physical handheld device to define the ratio of bone geometry to per bone, bone topology, and rigid global transformations. Reducing or eliminating user interaction remains an issue that needs to be addressed.

Another exception occurs in the pipeline of automatic rigging [8]. Bharai and his colleagues extracted the skeleton of a shape made up of many connected parts that, in general, could not match the animation capture output or the animator. Considering these cases, extracting the existing input skeleton and the output are graphically matched.

3.2. Automatic cages

Skeletons aren't the only way to exert control over structures. Cage-based deformation is a subset of linear mixed skin. The main research area of cage deformation is Generalized barycentric coordinates, which have been gradually developed in the past decade [40], [41], [61]. A triangular polyhedron is defined by most cage-based approaches (i.e., a cage is a closed, manifold triangular grid) and a cage-based polyhedron [31], [56], [57], [61].

The artificial quad-dominant meshes will make it more unstructured and compact than the manual four-dominant mesh. Cage-based methods can be generalized to arbitrary polyhedra [37], [40]. Various planarization algorithms have been generated in architectural modeling to find the planar quadrilateral grid closest to the input quadrilateral [13], [73], [86]. These methods add plane constraints and can help to design the deformed polyhedral cage better.

3.3. Automatic handles during modeling

If you want to avoid some problems associated with cage construction or skeleton, you create control structures and shapes simultaneously, but this requires maintaining the skeleton and cage throughout the editing operation.

Subdivision control cages are unsuitable for direct use as low-frequency deformation cages because they are directly associated with the shape details. [10] propose a comprehensive solution. Their system is based on sketching modeling software.

3.4. Automatic curves, regions, and points

In addition to handle types such as skeleton and cage, there are several other handle types. In design, automatic curves are a common processing method for editing a given shape [28], [78], which defines the boundary of the smooth part and the point of intersection with other parts.

Curves can be extracted from CAD for man-made objects, and if not, more powerful techniques require more complex shapes [53], [70]. Curves are important to our shape perception [18]. Besides, schemali [78] found curvilinear handles resembling skinning deformations. Dots get a lot of attention as the easiest gamepad to reach by placing, but unfortunately, users have no control over them.

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3.5. Euclidean-distance based weights

As a user page, the handle should control the shape area within its range. With good interpolation operations, we can operate directly using user interface terminology [79]. A variant of Shepard interpolation is used in automatic weighting based on inverse Euclidean distance.

In practice, it is easier to use user interfaces when using cages and generalized barycentric coordinates as subspaces for reduction, e.g., points [7], [11], [87], [93], [94] or skeleton [41] to indirectly embed the shape and position the cage. In conclusion, generalized barycentric coordinates are a very attractive field for scholars to study, and their application frequency goes beyond (perhaps more than) shape deformation.

3.6. Quadratic smoothness energies

Unlike linear blend skinning, which is linear variational modeling caused by quadratic energy minimization, we can solve the problem by studying these techniques. One assumption is that the optimal deformation is fair without any prior information about the physical material of the shape.

These levels of continuity are only seen in the limits and constrain the boundaries of continuity when we consider only the case [12], [36]. These energies are discretized using finite elements methods on triangular and tetrahedral grids. Moreover, the only reasonable deformation is caused by a displacement that minimizes some energy.

3.7. Desirable qualities for skinning weights

The skinning has traditionally been controlled by the bones, but an ideal auto-weighting approach requires a consistent framework that supports all Generic handle types, such as regions, cages, and points. In addition, even perfectly smooth weights can cause violent oscillations, affecting the user's non-intuitive response to the handle.

Finally, automatic methods will replace the tedious manual weight drawing. When using the automatic method, the ring rigging is still an interactive process. In addition, the ability to quickly calculate mass weights (SPEED) will also be available for new applications (e.g., physics-based contact, fracture simulations, see [23], [29], [39]).

4. Example-based Shape Deformation

The instance-based approach has two main characteristics: skinning usually uses a short algorithm to specify the vertex deformation position. Historically, animation has been abstracted as a function of time. Example-based skinning (EBS) approaches have obvious advantages and disadvantages. First, the required deformations are sculpted directly, and algorithmic skinning approaches usually only need to specify parameters related to the desired shape. Second, the exemplar-based approach allows for a strategy of progressive refinement, adding additional shapes as needed to get the desired quality. However, one of the disadvantages of EBS is that it needs to take into account the high-dimensional pose space, and EBS requires calculation proportional to the number of instances, which makes the computation required higher than the algorithm skinning. Finally, EBS needs to recognize the numerical considerations (including regularization and dimension curse) in interpolation and data fitting. Finally, skinning is a central component of the theme ‘Rigging’. There are also investigations of facial manipulation and personality [64], [71].

4.1. Pose Space Deformation

The artist moves the underlying skeleton to certain postures and sculpts an example of the desired shape on these postures using the Postural Space Deformation (PSD) algorithm. [54]. Sloan [82] refer to these freedom degrees as ‘adjectives.’

In general, PSD is applied to the rigid transformation of surfaces or correction or migration of the underlying skin systems (like dual-quaternion skinning [68]; spherical skinning [96]; linear blend skinning (LBS) [54]). When implementing PSD systems within the software, existing skin and rigging operations like those in Maya, have more complex algorithms or proprietary ‘black box’ deformers. The idea of using derivative - free optimization to reverse any existing skinned rig was proposed by [95].

The following three points are both related and different:

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Per-shape or per-vertex interpolation. Shape-by-example using in the cardinality interpolation of the example, where all vertices of the example grid will be applied with the same weight [82].

In the pose space, interpolation can be local or global. A single global pose space can be formed from all the degrees of freedom connected to the model. Conceptually, to solve the problem of every desired arm shape, you can add examples of legs in all possible shapes.

Interpolation algorithm. Different scattered interpolation algorithms can be adapted to any vertex - or shape-by-vertex interpolation, local or global in the attitude space.

4.2. Shape by Example

At the 2001 I3D conference, Sloan, Rose and Cohen presented a technique was exemplified by shaping [82]. This technique has something in common with PSD, except that interpolation is expressed as a basic interpolation of instances in composing space.

The use of cardinality interpolation has two advantages. First, it is easier to use global pose space for all examples. Second, efficiency is significantly improved when separate, per-vertex interpolation effects are not required. The concept of pseudo-examples is another innovation of this work. In this method, instead of sculpting new examples of interpolating shapes and simply moving them to a new position in the gesture space, the artist finds an acceptable interpolated shape in the abstract gesture space, then the result will be that the gesture space itself is reshaped.

4.3. Weighted Pose Space Deformation

The weighted Postural Space deformation (WPSD) algorithm was proposed by Kurihara and Miyata [50]. The WPSD algorithm greatly reduces the number of samples required and solves the dimension curse to some extent.

Kurihara and Miyata combined normalized radial basis functions and used cardinal interpolation schemes.

4.4. Context-Aware Skeletal Shape Deformation

Weber [92] is a combination of weighted postural space deformation [50] and deformation transfer [84]. The WPSD will mix triangles from examples in the rest of the space, which is transformed by the rigid body motion of the skeleton using a deformation-transfer approach.

5. Direct Delta Mush Skinning（DDM）

DDM inherits the benefits of DM while also greatly accelerating the computation speed, allowing it to be approximate while also meeting the algorithm's speed, quality, and simplicity requirements. DM [62] has been sped up, set up, and has the characteristics of being simple, suitable for non-real-time applications, and avoiding the skin-before-algorithm in most undesirable folding and artifacts. In terms of speed, computations are in the traditional skinning range, the number of operations is significantly reduced compared to DM, and the CPU can quickly run complex characters in real-time. In terms of quality, general deformation types are provided as well as DM. In terms of creation, there is no effort required to achieve acceptable results, and local control of the degree of smoothness or blending is provided. In particular, DDM has an explicit decomposition into rotation and translation, enabling the simple simulation of skin sliding effects that are impossible with existing geometric skinning algorithms.

6. Discussion

6.1. Comparison of three methods

Direct Skinning Methods, in the direct skinning methods, we compare linear blend skinning with dual quaternion skinning and Rest Pose from different angles and aspects. Here is an example in Figure 1-5.

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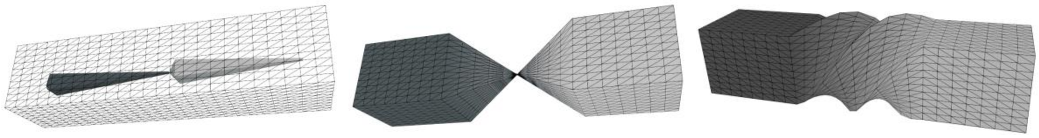
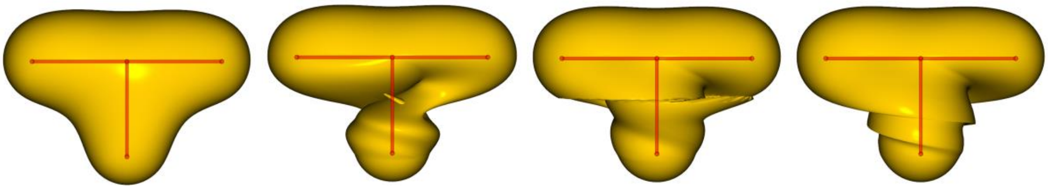


Rest pose Linear blend skinning Dual quaternion skinning

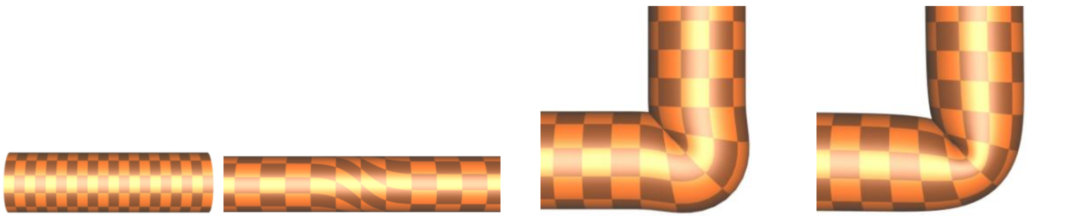
Figure 1: There is an adjustable rod and two bones in the resting position (left). The right half of the bone is twisted 180 degrees (light gray) resulting in the candy packing workpiece (middle). Using dual quaternion skins can help to avoid this behavior (right). [2014 SIGcourse direct skinning methods and deformation primitives].



Rest pose Linear blending Dual quaternion blending Differential blending

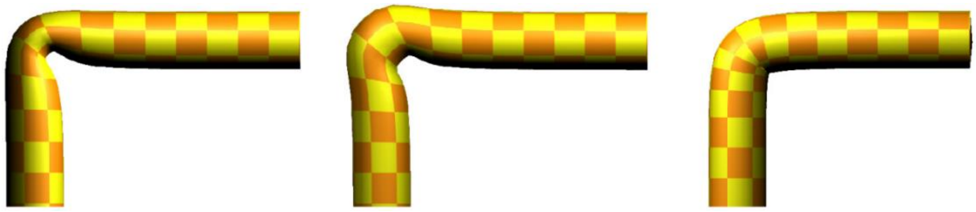
Figure 2: Creating a spiral deformation will fail due to a mixture of linear and dual quaternions. But multiple revolutions will handle differential mixing correctly. [2014 SIGcourse direct skinning methods and deformation primitives].

Bulging artifacts are a type of problem with dual quaternion skinning. [43], [48]. Although this method works well when twisting the cylinder, it produces some unnatural bulging effects when bending.



Rest pose Dual quaternions: twist Dual quaternions: bend Elasticity-inspired deformers

Figure3: An example of the bulging effect of biquaternion in bending a cylinder. And elastic deformers avoid this problem [43]. [2014 SIGcourse direct skinning methods and deformation primitives].



Linear blend skinning Dual quaternion skinning Spline skinning

Figure 4: Comparison of deformation control effect between spline skinning and linear and dual quaternion skinning. [2014 SIGcourse direct skinning methods and deformation primitives].

Kavan and Sorkine [43] proposed the general concept of joint-based deformable bodies.

Rest pose Linear bland skinning Dual quaternion skinning Stretchable-twistable bones

Figure 5: Flexible and torsional bones [43] unlike linear and dual quaternion peeling, it allows us to expand and deform along the length of the bones. [2014 SIGcourse direct skinning methods and deformation primitives].

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Table1: Comparison of linear blend skinning and dual quaternion skinning under limited conditions.

	Whether there is" a Candy wrapper artifact appears"	Is the parameter finite	Whether a spiral deformation can be created	Whether the model is convex when bent
Linear blend skinning	yes	Yes	No	No
Dual quaternion skinning	No	Yes	No	Yes

Automatic skinning methods, the automatic skin section describes the various branches involved, such as the skeleton, cage, various types of handles, skin weights, etc. In the introduction, skin piping has been divided into three steps, exploring automatic handle creation and automatic skin weight calculation. Here are some graphical additions to the text, as shown in Table 1.

Skeletons are almost as old as computer animation, and the aforementioned effects are viewed as secondary (e.g. [59]). And also, traditional animation textbooks ask draw the skeleton of the character before determining the pose (see Figure 6).

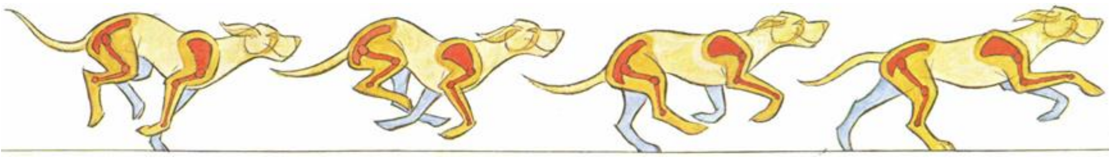

Figure 6: Traditional animators find a pose by drawing an inner skeleton, sometimes just the limbs to suggest the rest of the shape. [2014 SIGcourse automatic skinning via constrained energy optimization].

One flow-based approach utilizes the convergence of surface flow on the internal curve skeleton. It is observed in the prototype method that surfaces that undergo mean-curvature flows tend to degrade the cylindrical portion of the shape to thin lines (see Figure 7).

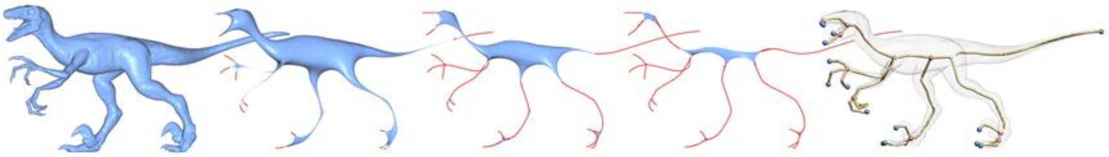

Figure 7: Successive Laplacian smoothing and joint clustering converge to an internal skeleton [4]. [2014 SIGcourse automatic skinning via constrained energy optimization].

The rows in Table 2 represent alternative definitions of generalized barycentric coordinates or weighting functions.

Table2: Feature chart for generalized barycentric coordinates. All methods are deficient in one way or another [2014 SIGcourse automatic skinning via constrained energy optimization].

Method	N- GON	C ONCAVE	S HAPE	≥ 0	CLOSED	Out	LOCAL	POLY	COORD.
Barycentric	X	X	•	•	•	•	X	X	•
Wachspress	•	X	•	X	•	?	X	X	•
Natural Neighbor	•	•	X	•	•	•	•	•	•
Mean Value	•	•	•	X	•	•	X	X	•
Green and others	•	•	•	X	•	X	X	X	•
Positive Mean Value	•	•	•	•	X	X	X	X	•
Harmonic	•	•	•	•	X	X	X	•	•
Maximum Entropy	•	•	•	•	X	X	X	•	•
Total Variation	•	•	•	?	X	X	•	•	•
Const. Biharmonic	•	•	•	•	X	X	•	•	X

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Example-based Shape Deformation approach will create skinning and other effects by inserting a series of sculpted or scanned examples of the desired deformations in the 'pose space' defined by joint angles and other degrees of freedom of the physiological equipment, as shown in Figure 8, Figure 9.

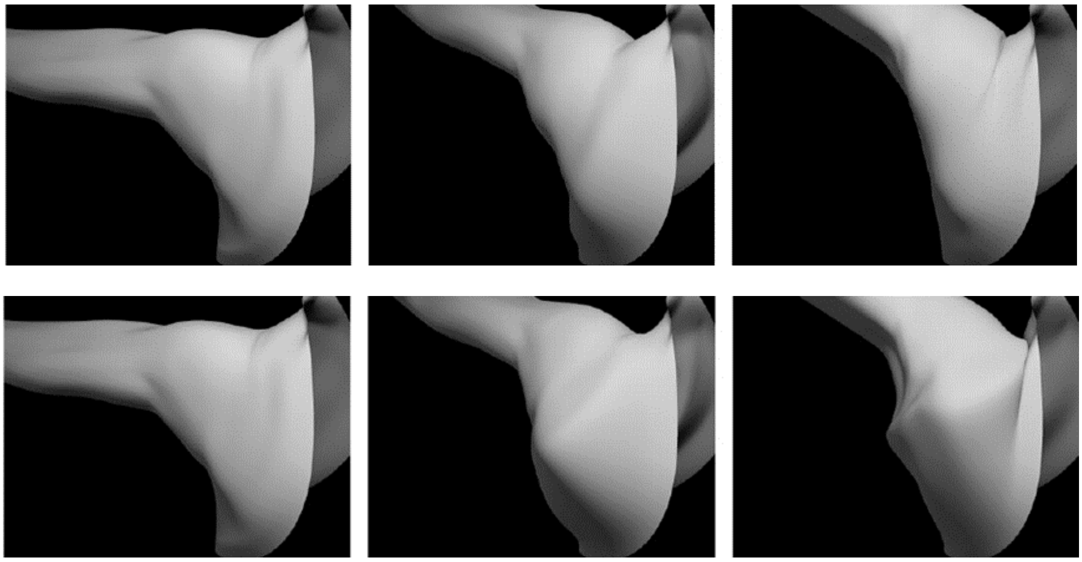

Figure 8: Comparison of PSD and LBS on the shoulder. At the top, the PSD only uses two sculpture poses. At the bottom, LBS shows a bigger problem in the rotation of the shoulders. [2014 SIGcourse example-based shape deformation].

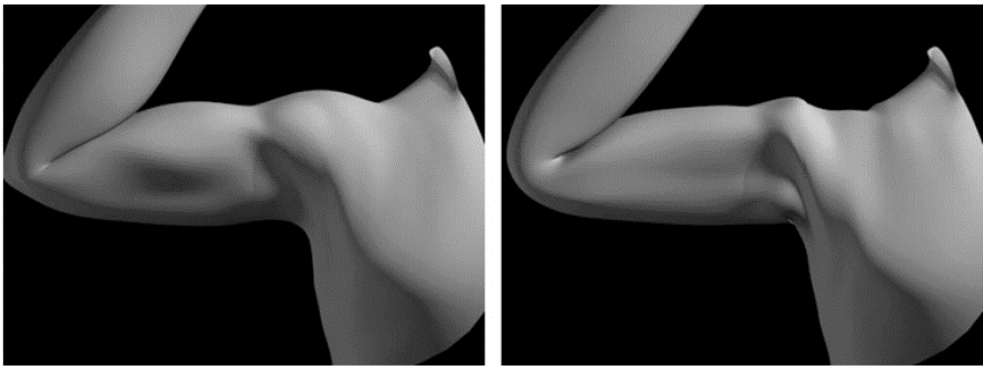

Figure 9: Comparison of PSD (at left) and LBS on the extreme pose of an elbow. [2014 SIGcourse example-based shape deformation].

The shape of the example in [50] is very believable and detailed because it was captured by a medical scan of one of the authors' hands (Fig. 10).

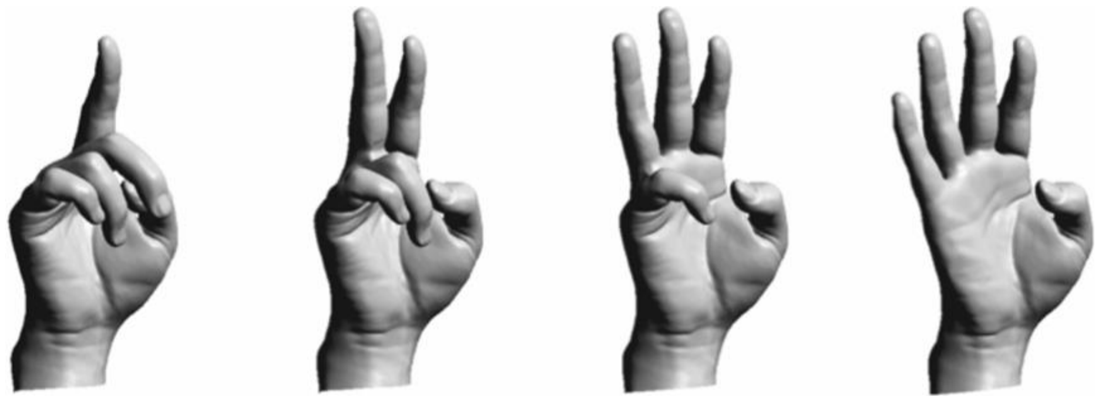

Figure 10: Hand poses synthesized using weighted pose space deformation (image from [50] © Tsuneya Kurihara). [2014 SIGcourse example-based shape deformation].

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Table 3: About the comparison of data between four different algorithms.

Algorithm	Large deformation range	The high amount of calculation	There are numerical limits	Additional algorithms are required	Avoid the curse of dimensionality
EBS	•	•	•	•	/
PSD	/	/	/	/	•
LBS	/	/	/	/	/
WSPD	/	X	/	/	•

6.2. Future trends

In the section on direct skinning, we introduce the main trends in direct skinning methods. Blend skinning methods include spherical blend skinning [44], log-matrix blending [1], [60], LBS [59], optimized centers of rotation skinning (CoR) [9], and dual quaternion skinning (DQS) [45]. These methods are fast, convenient, and easily mapped to GPU hardware, and are available in most software packages. Although these methods have some common drawbacks, they are widely used in some interactive applications and games, as shown in Table 3.

In addition to the applications described above, there are several other applications. Shape-modifying methods, for example feature skins [49] and pose space deformations calculate deformation geometry by interpolating instance shapes than using algorithmic deformations [54], [82]. Implicit skilling [90] provides a relatively inexpensive solution for local auto collisions without the need for full physical simulations, which is sufficient for animation editing and previewing. Simulation methods [3], [20], [21], [22], [51], [58], [63], [75], [77], [83] provide critical additional effects like bumping, volume retention bulges, jitter, skin slippage, and folds. Analog methods are only suitable for off-line production, such as Weta Digital's organizational system or Maya Muscle, however, thanks to recent methods [14], [17], [19], [55], [97]. These methods are particularly well suited to producing dynamic effects (vibrations) and quasi-static deformation types that are impossible with low-cost skin methods.

At present, the skinning algorithm is the most widely used in entertainment. However, the skinning algorithm is prone to "collapse" and "candy wrapper" effects, among which "collapse" refers to the flattening and penetrating problems caused by the skin when the joints are bent. The same thing happens when you bend a hollow steel pipe." The "sugar-wrapper effect" refers to the thinning of the skin at the joints when the skin is twisted along the bone axis. Similar to what happens when you twist candy paper. The root cause of these issues is ignoring the physical structure, such as muscle between bone and skin, and only considering the skeleton and skin layers. However, skinning is still the most widely used skin deformation algorithm.

Furthermore, one of the significant challenges that computer animation faces is character modeling and skin technology, mainly for the following reasons: first, the human body has 200 degrees of freedom and very complex movement; Second, the shape of the human body is irregular, and changes with the change of muscles and expressions; Third, the primary audience and evaluator of computer animation is human itself, often with human's sense is unable to capture subtle differences. Therefore, although character modeling has been studied for almost as long as skin technology, it is still a huge problem, which is also worth further study by researchers.

7. Conclusions

As an important research content in computer animation, character animation involves a wide range of content, among which skin technology is the leading research content of character animation. This paper introduces the main skin technology methods in the literature in recent years, classifying different skin technology is introduced, the principle and advantages and disadvantages of each method are described, and, at the same time, combined with the application needs to find the deficiency of current job, the solution of these problems, the application of skin technology in efficiency and quality of character animation will continue to improve, to promote the development of character animation in various fields, To promote the continuous development of various animation and film industries.

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