Animation Generation and Retargeting based on Physics Characteristics

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Abstract

Motion retargeting can be achieved by direct shape deformation transfer but may be visually unrealistic and physically incorrect. The purpose of this study is to include the consideration of physical properties for more realistic target motion synthesis. After partitioning source and target objects into segments, each segment mass and center of mass (COM) position/velocity are estimated. The target animation is generated by minimizing the difference in total linear momentum between source and target. Weighting functions for addressing the importance of segment motion and constraints on unrealistic segment length/velocity are also included. The results show that target movement amplitude and velocity are generally smaller than those of the source animation and with less seemly unrealistic motion. Thus, plausible animation can be generated by the retargeting procedures proposed in this study. The same methods may be applied to a variety of different target models for realistic motion synthesis.

1. Introduction

Generating realistic three-dimensional (3D) animation is one of the major topics in computer graphics. When all the vertices of the corresponding object move with time, motion of the object is generated. This kind of technology has been used in 3D simulation for film making and online games. However, without considering physically-based characteristics, animation generated by it may look awkward or unrealistic.

Recently, one popular topic in computer graphics is re-using [3] or even retargeting/transferring [5] existing animation onto different 3D models in order to create new animation. The sources of object/figure movements are usually motion capture systems. In general, source motions are modified slightly or corrected by blending techniques to create different styles and a sequence of movement.

Automatically generating a realistic motion sequence without relying too much on motion capture system is still a challenging task. The plausibility of simulated motion animation is judged by subjective observation of human eyes, but it is difficult to create seemly natural animation. For example, a final posture can be reached by a variety of different preceding movements, but only very few of them look natural [7]. One way for solving this problem is by making models satisfy physically-based conditions [1, 2]. However, the situation becomes increasingly complicated for complex multi-segment animal or human models.

In this study, in addition to applying deformation transfer on source animation to obtain target animation, several physically-based conditions are also introduced. First, each segment mass and center of mass (COM) position are estimated for both source and target models. Segment kinematic variables, such as velocity, acceleration, and total linear momentum are estimated as well. Next, it is assumed that target motion generally preserves the same or similar momentum values. In the optimization process [8] the control variables (segment COM positions) are adjusted such that target model has the assumed linear momentum values. In this way target motion is made similar to source animation and movement features of target object can be preserved as well.

Retargeting the animation of different 3D models and preserving physical conditions can be achieved by the method proposed in this study. This method is an improvement from using only deformation transfer technique which neglects target object physical properties. The combination of deformation transfer and the current method can be used to retarget existing animation onto other 3D models in order to enhance animation reusability.

2. Methods

This study focuses on analyzing and creating motion based on laws of physics. That is, utilizing the kinematics of each segment and the whole object to modify target animation such that physical constraints can be satisfied.

The motion to be analyzed comes from the source motion that is captured from real object/figure movement. The most frequently considered physical characteristics are mass distribution and linear/angular displacement and velocity.

2.1. Mass

Anamation models can be segmented by analyzing the degree of mesh deformantion between two nearby faces of an animation over all frames. The deforming mesh can then be partitioned into near-rigid components where segmentation boundaries always pass through regions of large deformation [6].

In order to estimate segment mass, a bounding box with the smallest size is used to enclose a segment. This bounding box can also be used for collision detection in other applications such as multi-object motion synthesis. Next, the box is divided into many small cubes (Fig. 1). With the assumed constant density, segment mass can be calculated by estimating its volume (number of cubes intersecting the segment) in the bounding box. More accurate estimation of segment mass can be achieved by using smaller cubes. Although not used in this study, estimation of angular momentum is also accomplished in a similar way.

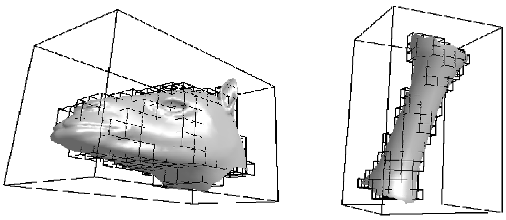


Figure 1. Estimation of segment mass

Segment mass is estimated by counting related cubes in the bounding box. This is done by determining whether each *dv* is inside the segment, as the following equation:

$$\int dv \Leftrightarrow \sum dxdydz \qquad (1)$$

2.2. B-Spline

Information provided by source animation are discrete frames of motion. In order to preserve the continuity in real motion, data values between adjacent frames are interpolated by cubic B-Spline functions. In this way the first and second order derivatives of the original data can be more accurately obtained. For example, linear/angular velocities are first order and linear/angular accelerations are second order derivatives of source animation (displacement data).

According to the above description, inertia and kinematics values can be obtained.

2.3. Optimization

In the optimization process, the objective function for generating realistic target motion is defined. The BFGS Quasi-Newton Method [4] is used for optimization. This method searches for the minimum value of the objective function using function gradient and approximated Hessian matrix (with second-order function derivatives).

2.3.1. BFGS Quasi-Newton Method. The basic idea of the method is to build up, iteratively, a good approximation to the inverse Hessian matrix A^{-1}, that is, to construct a sequence of matrices H_i satisfying:

$$\lim_{i\to\infty} H_i = A^{-1} \qquad (2)$$

Even better if the limit is achieved after N iterations instead of 1.

Newton's method finds the next iteration point by:

$$x - x_i = -A^{-1} \cdot \nabla f(x_i) \qquad (3)$$

The left-hand side is the finite step we need take to get to the minimum; the right-hand side is known once we have accumulated an accurate $H \approx A^{-1}$.

The idea behind quasi-Newton methods is to start with a positive definite, symmetric approximation to A (usually the unit matrix) and build up the approximating H_i's such that the matrix H_i remains positive definite and symmetric. Far from the minimum, this guarantees that we always move in a downhill direction. Close to the minimum, the updating formula approaches the true Hessian and we enjoy the quadratic convergence of Newton's method.

Subtracting equation (3) at $\mathbf{x}_{i+1}$ from that same equation at $\mathbf{x}_i$ gives

$$x_{i+1} - x_i = H_{i+1} \cdot \left(\nabla f_{i+1} - \nabla f_i\right) \qquad (4)$$

where $\nabla f_{i+1} \equiv \nabla f(x_i)$, and $H \approx A^{-1}$.

2.3.2. Objective function. In optimizing the target animation, the objective function consists of two terms. The first term assumes the similarity between the total momentum of the target and source motion. That is, the target total momentum is close to that of the source object when the total masses of the two objects are assumed to be nearly equal. If this is not the case, the COM velocities of both source and target objects are assumed to be the same and the total momentum is just the product of COM velocity and total mass. In addition, because the importance of motion visualization is different for each body segment, a weighting function is multiplied by each segment momentum. By minimizing the objective function *J*, the target animation is made close to the source motion with adequate consideration of its physical properties. The objective function *J* is shown in the following equation

$$J = \sum_t \left[\left\| M_{s,COM}(t,q) - M_{t,COM}(t,q) \right\|^2 + c \sum_i w_i \left\| M_s(t,q_i) - M_t(t,q_i) \right\|^2 \right]$$

2.3.3. Variables and Constaints. To reduce the number of variables in optimization, only linear momentum is considered in this study. Thus the number of optimizable variables are frame number times segment x, y, and z coordinates. That is, 24 frames × 14 partitions × 3 axes = 1008 in our experiments.

The optimization is also subject to two constraints. First, segment length (distance between adjacent segment COM positions) is assumed to change within a certain extent. Second, segment COM velocity cannot be unrealistically too big or too small.

3. Results

The source and target objects are a horse and a camel, respectively. Recorded realistic horse galloping motion is first retargeted onto the camel model by solely deformation transfer of the surface vertices. This original target motion is further modified by minimizing the objective function proposed in this study.

Figure 2 shows a frame with the largest difference between the motion generated by deformation transfer and by our proposed method. A sequence of motion is also compared (Fig. 3). Due to the similarity between the original and modified target motion (Fig. 4) for most of the frames, discussion will focus more on the frames with noticeable differences after object physical characteristics are considered..

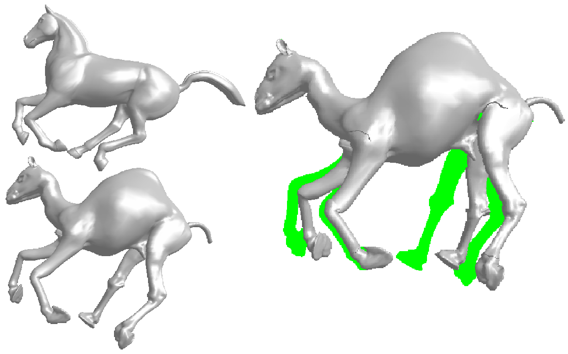
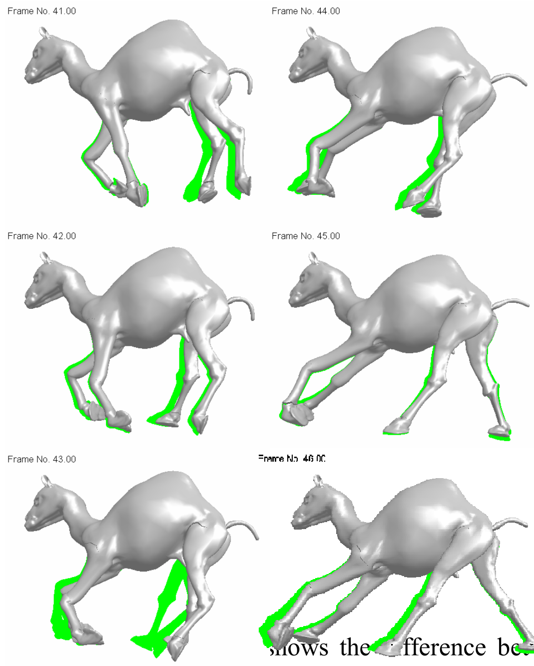


Figure 2. A comparison of the same frame of three different motion. Top left: source motion. Bottom left: target motion generated by deformation transfer. Right: Modified target motion with the current method. The green color shows the original target motion for better comparison.



[illegible] shows the [illegible]fference be[illegible]ween the original target motion (green) and the corrected target motion (gray) in sequent frames.

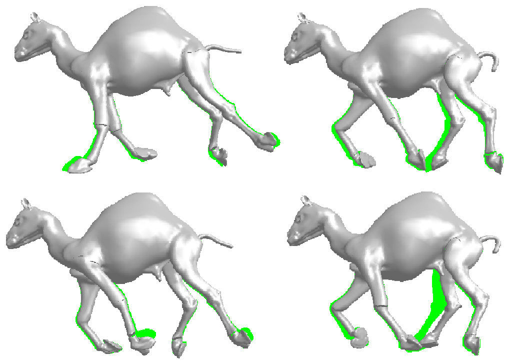


Figure 4. For most of the frames there are only slight differences between the motion generated by solely deformation transfer and by the current method.

In general target movement amplitude and velocity are smaller than those of the source animation, especially for the forelimbs. Although judging whether a sequence of motion looks natural is subjective, some visually weird motion frames seem to be more plausible after applying the presented technique.

4. Discussion and conclusions

Because there is not too much difference between the shapes of the target and source figures, modified target motion is still similar to the motion generated by deformation transfer. Although it is difficult to claim any significant improvement in the modified motion for the current example, we believe that this method will yield more plausible results for considerably different target models.

In the optimization process the current method considers only linear momentum with segment COM positions as control variables. Although plausible animation results can be obtained, it is expected that including angular momentum will lead to more realistic motion. Thus, the hierarchical angular relationship between segments will be considered in future studies. Because most joints have only one or less than three degrees of freedom and segment COM positions can be expressed as joint angles and segment lengths, the number of optimizable variables can be further reduced. Moreover, the constraints on segment length and COM velocity may not be necessary when joint angle, angular velocity and angular momentum are introduced to the optimization process.

In addition, biomechanical characteristics of different animals neglected currently should be considered in later studies. For example, joint ranges of motion for different animals are different. Constraints on range of motion for preventing joint hyperextension should be necessary. For movements requiring balance maintenance (such as walking), consideration of total body COM position within ground support area can also be added to increase motion validity.

In conclusion, plausible animation can be generated by the retargeting procedures proposed in this study. The advantage of applying this technique is expected to be more obvious if the shape of target object is a lot different from the source object. Methods in this study may be applied to a variety of different target models for realistic motion synthesis.

5. Acknowledgements

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