Energy-based Pose Unfolding and Interpolation for 3D Articulated Characters

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Abstract. *In this paper, we show results of controlling a 3D articulated human body model by using a repulsive energy function. The idea is based on the energy-based unfolding and interpolation, which are guaranteed to produce intersection-free movements for closed 2D linkages. Here, we apply those approaches for articulated characters in 3D space. We present the results of two experiments. In the initial experiment, starting from a posture that the body limbs are tangled with each other, the body is controlled to unfold tangles and straighten the limbs by moving the body in the gradient direction of an energy function based on the distance between two arbitrary linkages. In the second experiment, two different postures of limbs being tangled are interpolated by guiding the body using the energy function. We show that intersection free movements can be synthesized even when starting from complex postures that the limbs are intertwined with each other. At the end of the paper, we discuss about the limitations of the method and future possibilities of this approach.*

Keywords: Character animation, Motion planning, Pose interpolation

1 Introduction

Controlling characters that are closely interacting with its own body, other characters and the environment is a difficult problem. As the joint angle representation, which is the most prevalent way to express the posture of characters, does not consider the spatial relationship of the body limbs, the resultant movements suffer from collisions and penetrations.

In this paper, we present the results of controlling a character by using a repulsive energy function that has been successfully applied to control 2D linkages for unfolding [3] and interpolating [12] different configurations. We define a similar energy function used in [3, 12] that is based on the Euclidian distance of the linkages of character skeletons in 3 dimensional space.

We show the results of two experiments, which are the 3D and open linkage versions of what are done in [3] and [12]. In the first experiment, starting from a posture in which the limbs of the body are tangled with each other, the character is controlled in the gradient direction of the energy function and the limbs are successfully unfolded (see Figure 3). Next, we interpolate two different postures in which the limbs are tangled with each other. For several pair of postures, we can successfully interpolate them without any collisions or penetrations of the limbs (see Figure 4). These preliminary results hint the possibility to use the repulsive energy function for path planning and motion synthesis.

The rest of the paper is composed as follows. In section 2, we review some related work of motion synthesis. In section 3, we describe about the energy function that we define to control the character. In section 4, we show the experimental results of unfolding postures in which the limbs are closely interacting with one another. In section 5, we describe the algorithm and experimental results of interpolating different postures by using this energy function. In section 6, we discuss about the problems of the method and the possible approaches for coping with the problem, and conclude the paper.

2 Related Works

Simulating the close interactions of multiple characters is an interest of many researchers in character animation. We first review some work in the field. We then review path-planning methods for synthesizing movements of close interactions. Finally, we give a brief review of some work in computational geometry that handles problems of unfolding and interpolation.

2.1 Character interaction

The simulation of interactions between multiple characters has many applications such as computer games, virtual environments and films. Liu et al.[16] simulate the close dense interactions of two characters by repetitively updating the motion of each character by spacetime constraints. Lee and Lee [15] simulate the boxing match by using reinforcement learning. Treuille et al [20] use reinforcement learning to simulate the pedestrians avoiding each other. Shum et al [17, 19] use min-max search to find the optimal action in a competitive environment. They also propose a real-time approach based on an automatically produced finite state machine [18]. These researches do not handle very close interactions such as holding or wrestling. Ho and Komura [9] propose to evaluate the similarity of character postures based on the topological relationships. When equivalent postures are found, the postures are linearly interpolated at the level of generalized coordinates. In [8], Ho and Komura define a new coordinate system called Topology Coordinates to synthesize and interpolate keyframes in which the characters tangle their limbs with each other. The method is applied for a prototype of a wrestling game in [10]. The postures are restricted to those involve tangling and it is not very suitable when there is no tangle between the characters.

2.2 Path-planning movements of close interactions

Up to now, if we want to generate scenes of close contacts such as one character holds, carries or wrestles with another, it is necessary to plan the motions by

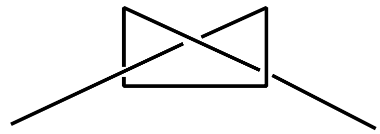

Fig. 1. An example of a locked 5 link chain.

global path planning / collision avoidance approaches, such as Rapidly-exploring Random Trees (RRT) [14] or Probabilistic Road Maps (PRM) [13]. Yamane et al. [21] simulate motions to move luggage from one place to another by combining IK and RRT. Hirano et al [6] and Berenson et al. [1] propose to use RRT to search the state space for grasping objects. Ho and Komura [7] use RRT to plan motions such as holding and piggybacking. The problems of global planning methods are (1) they require a huge amount of computation to find collision free paths, (2) as the paths are randomly searched, they are not consistent, and (3) the resulting motion requires further refinement such as smoothing due to its jaggyness. Therefore, these approaches are not practical from the viewpoint of interactive character motion synthesis and editing.

2.3 Linkage unfolding in computational geometry

In computational geometry, a number of researchers have been motivated by the question about locked chains. The main question is which types of linkages always have connected configuration spaces [5]. If the configuration is connected, it is called unlocked, and any two configurations can be interpolated. On the contrary, if there are disconnected configurations, it is called locked. In 3D, a locked open chain of five links was found by Cantarella and Johnson [2] (see Figure 1). In [4], Connelly et al. prove that there are no locked 2D chains. Upon this discovery, Cantarella et al. [3] propose an energy-driven approach to unfold linkages, and Iben et al. [12] propose an extended approach to interpolate arbitrary configurations. We apply these approaches for unfolding and interpolating postures of 3D articulated characters. Although it is proven that there can be locked configurations for 3D articulated characters, we show that this approach works well for various complex postures which we observe in daily life.

3 Unfolding the Body by Repulsive Energy

In this section, we first explain about the repulsive energy function that we use for the experiments in this paper. Next we show experimental results of unfolding a folded body posture by moving the body in the gradient direction of this energy function.

3.1 Repulsive Energy

The repulsive energy move each body segment away from each other. We design the energy such that it converges to infinity when the distance between two segments decrease to zero:

$$G = \sum_{i,j,i \neq j} E(q_i, q_j) = \frac{1}{D(q_i, q_j)} \tag{1}$$

where q_i, q_j are the configurations of the two body segments, and $D(q_i, q_j)$ is the shortest distance between the two body segments. We use this function to guide the character to either unfold from a folded posture and interpolate two different postures. The energy becomes larger when the body is folded and will be smaller when all the limbs are stretched out, as shown in Figure 2.

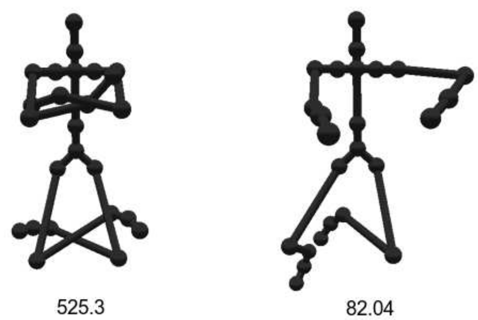

Fig. 2. A folded posture (left) and an unfolded posture (right), and their repulsive energies shown at the bottom of each posture.

3.2 Unfolding Folded Postures

We use the energy function defined in Eq.1 to unfold the postures. Starting from various folded postures in which the limbs are tangled with one another, the Jacobian of the repulsive energy is computed, and the body posture is updated by moving the joint angles in the gradient direction. The updates of the body joint angles are computed by the following equation:

$$\Delta q = (-I + JJ^T)\frac{J}{\|J\|} \tag{2}$$

where q is the vector of joint angles and J is the Jacobian of the repulsive energy G: $J = \frac{\partial G}{\partial q}$. After solving Δq, it can be normalized and used to update q: $q := q + \Delta q$. However, we also need to consider other constraints, such as positional constraints and joint limits. Here we linearize the nonlinear constraints and turn inequality constraints into equality constraints by imposing them only when the original inequality constraints are violated [11]. Let us represent all the linear constraints by

$$K\Delta q = C. \tag{3}$$

Then, we project the original Δq onto the null space of these constraints by:

$$\Delta q' = \Delta q - K^T l \tag{4}$$

where

$$l = (KK^T)^{-1}(K\Delta q + \alpha\epsilon), \tag{5}$$

α is constant whose value is set to 0.01 in our experiments and $\epsilon = K\Delta q - C$. Sometimes, after projection, $\Delta q'$ might be facing the gradient direction, i.e., $J \cdot \Delta q' > 0$. In such a case, we need to update $\Delta q'$ by a further projection:

$$\Delta q'' = \Delta q' - D^T l' \tag{6}$$

where

$$l' = (DD^T)^{-1}(D\Delta q' + \alpha\gamma) \tag{7}$$

$$D = \begin{bmatrix} K \\ G \end{bmatrix}, \gamma = \begin{bmatrix} \epsilon \\ \sigma/\alpha \end{bmatrix}, \tag{8}$$

and σ is a small negative value which is set to -0.01 in our experiments.

Starting from various configurations shown in the left-most column in Figure 3, the body can be unfolded into postures shown in the right-most column. It can be observed that the body can succesfully unfold the limbs in these examples.

Although the unfolding is known to always converge for 2D linkages [3], this is not always the case in 3D. This is simply because simply moving the body in the gradient of a repulsive energy can fall into local minima especially when the limbs are making knots with each other. However, we have not faced such situations in our experiments, even for a very complex yoga pose shown in the bottom of Figure 3.

4 Interpolating Postures by the Repulsive Energy

In this section, we present the method and the experimental results of interpolating different postures using the repulsive energy defined in section 3.1. We are applying the algorithm of interpolating arbitrary configurations by 2D linkages [12] to 3 dimensional tree structures.

4.1 Methodology

Assume we are interpolating two different postures represented by q_1 and q_2. The algorithm proceeds by iteratively updating the two postures such that they approach towards each other. Again we assume there are linear constraints imposed

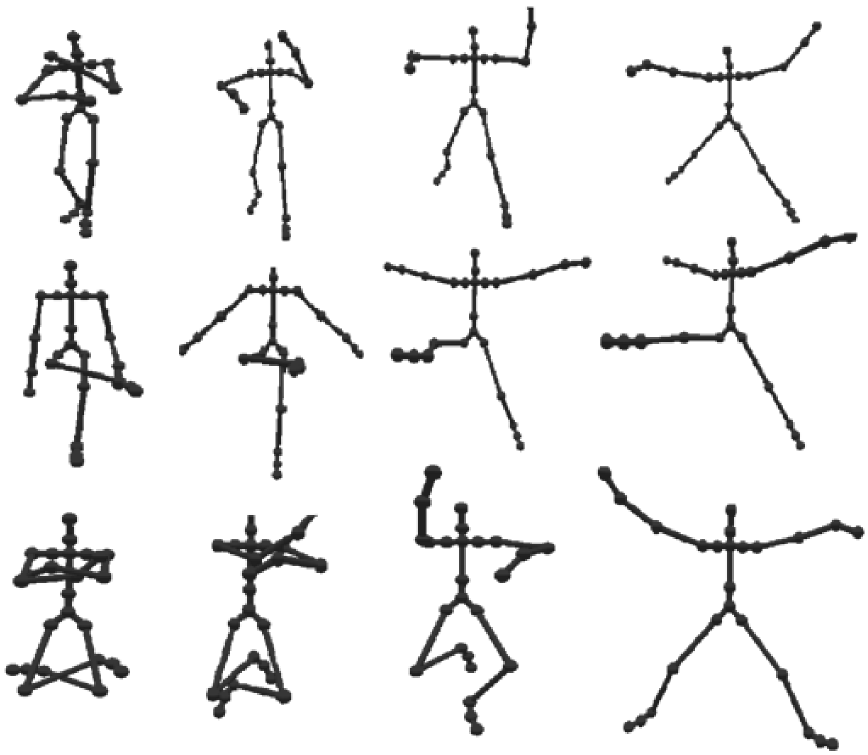

Fig. 3. Examples of unfolding movements starting from postures in the left

to the system represented by Eq.3. In each iteration, we first examine the energy of two postures, then move the posture with the higher energy, say q_h, towards the lower one, say q_l. We first calculate the update vector: $\Delta q = q_l - q_h$. Since moving along this direction could violate some linear constraints, we project the vector to the null space of the constraints by Eq. 4. Because moving in this direction might increase the repulsive energy, we apply another projection by Eq. 6. If such a direction cannot be found (if DD^T in Eq.7 is not invertible), we project the gradient-descent direction vector of the energy to the null space of the linear constraints. Once the update vector is calculated, we move q_h along this direction by a small amount.

Below is the pseudo code of the interpolation algorithm:

1. Initialization: $q_1 \leftarrow q_1^0$ and $q_2 \leftarrow q_2^0$.
2. Compute the energy G_1 and G_2 at q_1 and q_2 by Eq.1
3. $\Delta q \leftarrow sign(G_2 - G_1)(q_1 - q_2)$
4. if$(G_1 > G_2)$ $\quad q \leftarrow q_1$ else $\quad q \leftarrow q_2$
5. Compute the Jacobian of G by partial difference : $J = \frac{\partial G}{\partial q}(q)$
6. Project Δq onto the null space of K by Eq. 4
7. if $(\Delta q \cdot J > 0)$
   if (DD^T in Eq.7 is not invertible) update Δq by Eq. 6
   else $\Delta q \leftarrow -J$, project Δq to the null space of K by Eq. 4
8. $q \leftarrow q + \beta \frac{\Delta q}{\|\Delta q\|}$ where β is a small constant.
9. if $(G_1 > G_2)$ $\quad q_1 \leftarrow q$ else $\quad q_2 \leftarrow q$
10. If q_1 and q_2 are close enough, terminate.
11. Go to step 2.

Once the algorithm is converged, a collision free path can be synthesized by connecting the trajectories of q_1 and q_2.

4.2 Experimental Results

Here we show results of interpolating two different postures explained in the previous subsection. The initial and final postures are shown in the left-most and right-most columns in Figure 4, respectively. The snapshots of the interpolated motions are shown in the middle columns. It can be observed that the postures can be interpolated without any collisions or penetrations. In our experiments, all different combinations of interpolations succeeded without getting stuck at local minima. It is to be noted that the interpolation of these postures using joint angles or joint positions can easily result in penetrations of the limbs in these examples.

5 Discussions and Conclusion

In this paper, we have shown experimental results of unfolding and interpolating tangled body postures using a repulsive energy function. Although intersection-free movements are assured for linkages in 2D, this is not the case for 3D skeletons

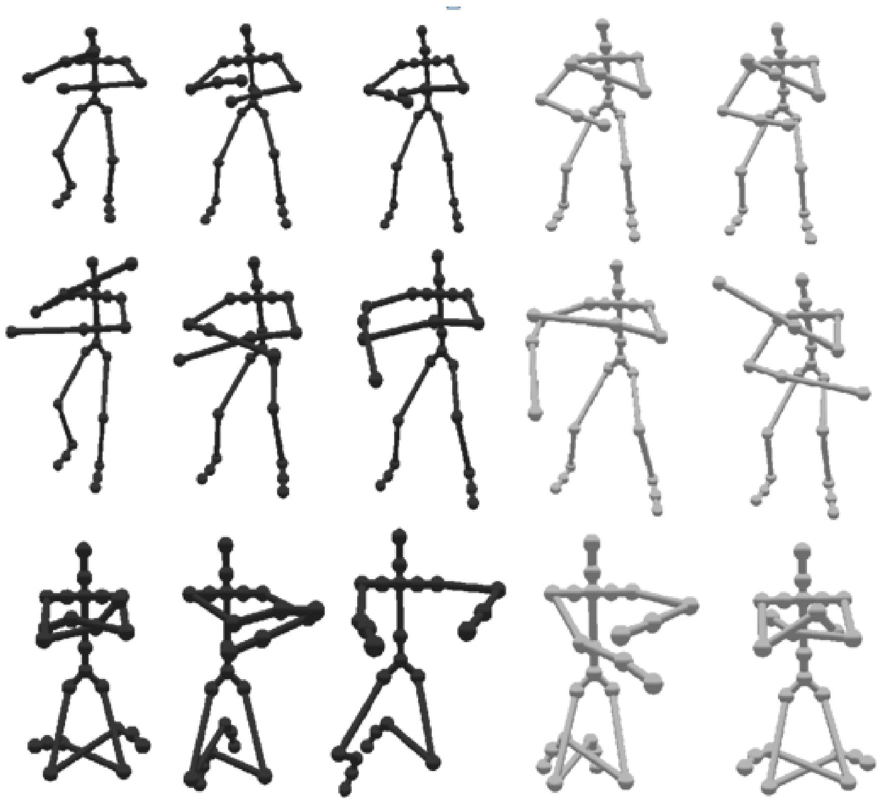

Fig. 4. Examples of interpolating two different poses.

due to locks and possible knotted postures. Despite the concern, valid movements can be synthesized in most of our experiments. This can be because the body limbs are only composed of three to four short linkages, which is not enough to compose complex knots. In order to unfold or interpolate configurations with complex knots, it will be necessary to analyze the postures and find out the knots, and control the limbs to desolve them.

One problem of the energy-based approach is that even the postures can be unfolded / interpolated in most of the cases, the motion synthesized is usually very dynamic and not realistic in terms of human movements. Producing natural smooth motions using the repulsive energy function can be an interesting research direction to follow.

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