Physical model of virtual human response motion captured in the taekwondo

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Abstract

Motion capture technology that sprang up in 1990s is widely used in assisted animation creation. The main work of this paper is to explore new ways for animation creation by capture data. Available technologies includes concurrent route composition based on taekwondo motion graph optimization, computer virtual puppet animation created by exploration of capturing motion, concurrent interactive control based on motion graph optimization and response motions of virtual characters. This article not only establishes a physical model of virtual human response motion captured in the taekwondo, but also establishes the motion frame changes for taekwondo characteristics.

Keywords: Taekwondo, Motion Capture, Motion Graph Optimization

1 Introduction

Since the late 1970s, motion capture technology began to be used in the three-dimensional computer animation, and has become one of the mainstream methods of making a three-dimensional computer animation. Three-dimensional computer animation based on motion capture is the mainstream of the current computer animation study, and is a hot topic in the field of computer graphics as well [1]. Early motion capture-based computer animation research focused on aspects such as sports editing and sports redirect [2-3]. The purpose of the former one is to develop a series of interactive methods to facilitate animator modify existing motion capture data, while the latter is committed to apply current motion capture data to different characters[4-6]. These early-proposed animation techniques have been successfully applied to a number of well-known commercial software, such as D3Mxa, Maya. However, on the basis of these technologies, animators still have to spend huge amounts effort to edit existing motion capture data for getting the desired animation.

Motion capture technology rose in the 1990s [7-8]. It greatly facilitates the creation of computer animation, especially for the three-dimensional animation. So far, the computer animation based on motion capture data has become a mainstream of three-dimensional animation creation. Currently, there are a lot of motion capture equipment manufacturers in the market, Vison motion systems [9] and Motion analysis systems [10] are representatives among it. From a technical point of view, this equipment can be broadly divided into mechanical equipment, electromagnetic equipment and optical equipment. Generally speaking, motion capture process requires following steps, as shown in Figure 1:

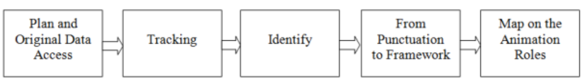

FIGURE 1 Motion capture process.

Application of early motion capture data mainly focused on the edition and variant of the existing and capture data, such as Wiki [11], Geiger [12]. Gradually, with the continuous improvement of the automation degree in editing, new motions were synthesized by capturing data, such as some scholars synthesized complex motion and motion editing based Motion Graph Path [13-14].

This article will focus on the data capture methods and original mathematical models of the taekwondo, and takes advantage of new editing method to improve the data capture technology of taekwondo.

2 Interactive route compositions

2.1 MOTION GRAPH CONSTITUTION

Mot1noGarph is an effective method synthesized by using data capture on the basis of specified path and constraints of users. Mot1noGarph can be broadly divided into two types according to the different contents represented by vertexes and edges. Due to intuition of the similarity between frames, a constructive approach is to regard a frame as a vertex. But in this way, some locality of the motion sequence cannot be directly used. Besides, construct graph directly on the frame data will cause a larger graph and uneasy to search which needs to stratify the graph or simplify the index. Therefore, in the process of Mot1noGarph construction, the edges represent motion sequences, vertexes represent jumping points existing between sequences. Sequences that represented by the edges are based on the division of the original sequences by jumping frame.

2.1.1 Form jumping points

We calculate by transforming it into a Euclidean space coordinates. The spatial location Pi of I joint (starting point of the bone) can be calculated based on the location of i-1 points. There is a recursive relationship:

$$\begin{cases} M_i = M_{i-1*} R_{i-1} + L_{i-1} \\ P_i = M_i * P_{i-1} \end{cases} \quad (1)$$

When calculating the similarity degree, we also need to consider several other aspects. What we compare is the similarity in posture, and it has nothing to do with the location of the human body. Therefore, we need to adjust the position and direction of the human body between the two frames carefully and make sure that the difference between them is minimal.Consequently, when calculating the similarity degree, the importance of each joint point is different. Therefore, we need to set weight for these joint points. Based on our intuition and experience, we use weights that synthesis with the aim of path in the experiment:

TABLE 1 The weight of each joint in the path synthesis, and the weight that was not listed is 0.

Joint	**Thigh**	**Shank**	**Foot**	**Low back**	**High back**	**Anocelia**	**Low neck**	**High neck**	**Brachial**	**Crank arm**
weight	0.4	1.0	0.1	0.8	0.1	0.1	0.1	0.8	0.4	0.2

In general, for a primitive sequence with n frame, the similarity matrix that we get through calculating the similarity degree of every two frames is shown in Figure 2. In the diagram, if two sub-sequences in the sequence are close to each other, then they will form a diagonal black stripe corresponding to the similarity matrix.

Establish joint point setting weights on the basis of taekwondo characteristics.

Because the speed similarity must be guaranteed of joints and frames used for smooth fusion cannot have much difference, so calculation of the similarity could be expanded into a window size range.

FIGURE 2 The similarity matrix part of the two action sequences. The higher the similarity is, the darker the corresponding points are. The triangular represents the local pole.

In summary, the function we adopted for calculation on differences between m frame and n frame is:

$$E(m,n) = \sum_{j=0}^{j=sw} \sum_{i=0}^{i=bn} wi\left(P\left(m+j-sw/2,i\right) - T\theta, l\left(m,n\right) P\left(n+j-sw/2,i\right)\right)^2 \quad (2)$$

2.1.2 Select Jumping Points

In similitude-difference matrix, jumping points are selected on the basis of threshold and local minimum. Thus in the first place quality of transitional animation can be guaranteed in jumping, and secondly, in concern of the complicity of balance graph, the graph is structurally simplified without losing its flexibility. Threshold is the key in quality control of jumping. Smaller threshold indicates fewer jumping choices and better jumping quality. Practically, different motion requires different threshold. For instance, thresholds for common motions are relatively lower to ensure vivid transitional motions, because humans are visually sensitive to this kind of motions.

2.1.3 Cut graph

At present, the graph cannot be traversed directly. Because given the unguaranteed connectedness, some parts can't be traversed or traversal may not go on for the lack of subsequent vertexes. Thus graph should be structurally revised to avoid the aforementioned cases. Dead vertex and sink vertex should be cut off for getting Strong Connected Component (SCC), as figure 3 shows. If many connected components in the present structure are found, then the largest component is to be adopted.

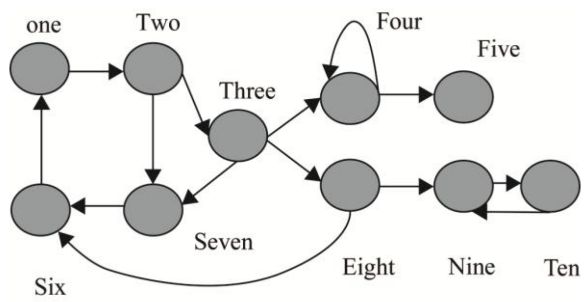

FIGURE 3 An illustration to cut motion graph: dead vertex 5 and sink vertexes 4, 9, 10 are to be cut off. SCC 1, 2, 3,6,7,8 are preserved.

2.1.4 Sequence interpolation

Motion data set can have a great influence in path synthesis. If only left-turned original sequence is given, the right-turned sequence on designated path cannot be paired. Through mirror reflection of left-turned data, right-turned sequence can be derived to expand original sequence.

Similarly, if only modest turns exist in original sequence, it takes lots of modest turns to get close to a sharp turn, causing big path deviation that breaks some situation restraints in application. In this case, interpolation of existing motion data can be applied to obtain favourable motion sequence. To maintain vividness to the fullest extent, two sequences for interpolation should be commensurate. Through calculating similarity degree of two random frames, a matrix of similarity degree of the two sequences can be obtained. In Figure 5, a gray graph partially illustrates the matrix. As walking is a rhythmic activity, local maximums of similarity degree are distributed in lines that parallel to the diagonal, as shown in yellow lines in Figure 5. In accordance with required interpolation effect, one yellow line is to be projected in dual directions of two sequences and corresponding frames are extracted. First, do position interpolation and posture interpolation. Second, preserve footmarks and move positions to footmarks. Last, make sequence smoothly within the scale of interpolation. Figure 4 shows the sequence resulting from two original sequences with interpolation parameter of 0.3.

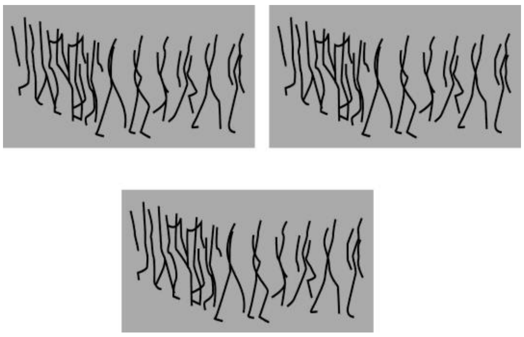

FIGURE 4 The sequence resulting from two original sequences with interpolation parameter of 0.3.

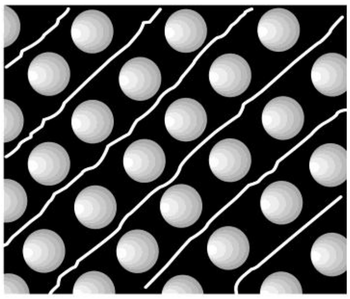

FIGURE 5 Two walking sequence similarity between two frames arbitrary. (Black similarity big, yellow marker sequence can match the interpolated)

2.2 APPLICATION OF THE MOT1NOGARPH

The application of the Mot1noGarph includes two stages: the extraction and synthesis of original sequence fragments. The extraction of original sequence fragments is a graph search process, but synthesis includes aspects such as smooth transition and constraint preserving.

2.2.1 Graph search

We marked displacement deviant and rotated angle on each edge of the sequence, along with relation of current points and corresponding points which greatly reduces the amount of computation.

2.2.2 Smooth transition

For obtaining smooth motion curve, first of all, align m-sequence and n-sequence of its window size, and then adjust the posture of the sequence ($T\theta, l(m,n)$). Lastly, linear interpolation to root joint should be done.

$$P'(m,n,i) = \alpha P_A(m,i) + (1-\alpha) P_B(n,i) \quad (3)$$

2.2.3 Constraint preserving

Generally, interpolation would causes phenomena that original potential constraint is broken, such as the food-sliding on the ground, toes pierced the ground. Therefore, when we do smooth motion curve, constraint transition should be done as well, namely to maintain continuity constraints. In the walking motion, the main point is to keep the Footprint constraints: First, the footprint constraints should be detected and flagged, then we choose constraint types according to the distance footprint from the ground: the former constraint sequence, the latter constraint sequence and new sequence generated in accordance with the former and latter constraints.

2.3 PATH SYNTHESIS

The applications of Mot1noGarph can be considered as a Mot1noGarph search process with constraints. Our mission is to search Mot1noGarph for forming designated action by users in accordance with users input. Many applications can be considered as Mot1noGarph search process with different constraints and halt conditions. For our Mot1noGarph, it is differ from general graph structures, such as: The edge between two vertexes may not be unique. For the path synthesis, namely synthetic route according to a user-specified action sequences, the definition is:

$$\phi(P_n - 1, e_n) = \sum_{k=n}^{n} \left| Pos'(s(ek)) - Pos(s(ek)) \right| \quad (4)$$

2.4 EXPERIENCE RESULT

Our taekwondo motion capture data is from the CMU motion capture database (moeap.CS.cmu.edu). The evaluation of the generated paths based on two aspects: one is the deviation degree (the ratio between target deviation and total frames of generated path), one is the average time generated path would take. As shown in Table 2.

Table 2

No	**Path shape**	**Path length**	**Time(s)**	**Bias ratio**
1	Shape of "8"	33	15	3.2
2	Shape of "cross"	130	40	2.3
3	Shape of "S"	50	21	3.1
4	Shape of "han" in grass writing	125	38	40.0

3 Interactive control and response motion of virtual character

We established an interactive taekwondo motion experiment. Firstly, we established a physical model of virtual character. Then, according to the features of taekwondo, we solved the following questions:

Interactive control: an interactive control based on Mot1noGarph is established for maintaining fluent interaction and harmonious animation;

Generation of response motion: we proposed solution in allusion to equilibrium-maintaining motion in the taekwondo.

3.1 ESTABLISHMENT OF VIRTUAL CHARACTER

In order to detect the momentum change of virtual human under disturbance, we need to build a mapping joint from motion capture data to the dynamic model. We connect the captured data to the human model with hinge structure. Among it, the size of virtual human body's each section is determined by the framework form capture data. The total mass of the virtual character we used is 65.Ikg. Each ball joint has a rotation angle and a twist constraint angle range; each rotary joint has a range of rotation constraint to express their freedom.

3.2 INTERACTIVE CONTROL

To improve the realism of the motion, the basic operation is driven by the motion capture data. Boxing action mainly divides into three categories, and these three categories establish the motion transition relationship as well as form a state machine similar to the upper Mot1noGarph. It can match the current category and use's designated category onto the vertex of Mot1noGarph. Then, a shortest path (Dijksrta algorithm) would be found between the two vertexes which can generate transition motion sequences that we need. We used different colors to mark the current position of Mot1noGarph in our experiment. Existing problems: in order to ensure a smooth transition, switch action that in response to user input may be slow, because the shortest path when searching was not actually short.

To improve motion vividness, all basic motions are driven by movement capture data. Generally, boxing can be divided into three categories, among which movement transitional relation is set. And a state machine similar with upper movement graph is formed:

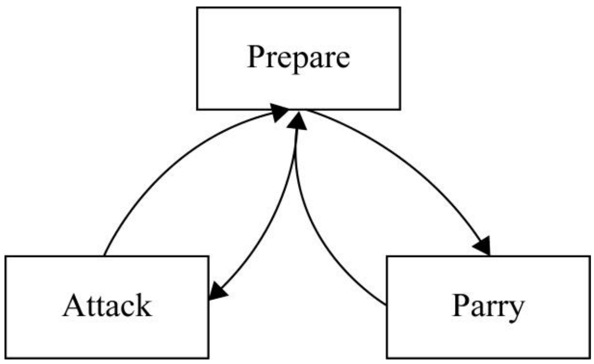

FIGURE 6 Transition of taekwondo.

Specify this framework on the basis of movement graph:

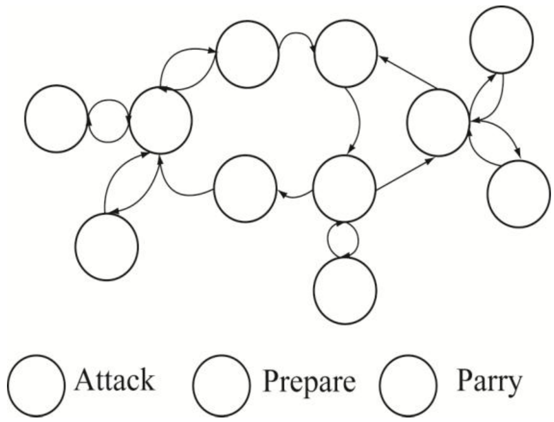

FIGURE 7. Movement graph of boxing.

3.3 ESTABLISHMENT OF VIRTUAL CHARACTER

Motion that we react to those external forces was called – response motion. We are particularly concerned to response motion that can maintain balance and do not fall to the floor, since these motions are relatively easy to amend for accommodating different sizes and directions of the external force. When a virtual character is subjected to an external force, it would cause rapid change the heart linear momentum and angular momentum around the virtual character. Use the momentum of change and motion data in joint similarity relations campaign from the campaign database search algorithm selects the most similar to the external disturbance response exercise, and the role of real-time correction based on the size and direction singled out in force in the virtual human body response to exercise, exercise and that it matches the external disturbance, the motion sequence and finally these two smoothly connected should exercise database of actions. The database contains a response action at different intensity and direction of the external force to the body. We applied directly to the magnitude and direction of the real people of different forces and capture his reaction to this external force action. Then the captured motion sequence reactions are classified according to the external force before and after the change in momentum. Then, based on user input hitting position, direction, intensity, we construct a vector to mark a position (Px, Py, Pz), direction.

The impulse size is f. Depending on the current position, we predict the state of equilibrium: extract a set of similarity search frame from the database, form a group of the deformation parameters based on the joint degrees of freedom and match the effect on adjacent frames to obtain a target posture.

3.4 SEARCH TO CAPTURE DATA

In the generation of response action, search can be used on the basis of similarity. Differ from value similarity of ordinary space posture, similarity based on momentum disturb also should be considered. Time cost would be huge if violent search is been done for each frame comparison from the database. Here we choose a dimensionality reduction method in accordance with intuition—

the multi-resolution bone structure levels: from left to right to reduce the joint points, from the original 32 to the final 6 joints are the same motions. The requirements of the body part are not the same rigor for different applications. Therefore, due to the weight of joint points can be taken in each search, so we apply a force to the right shoulder in the experiment. Different current position as well as the different direction and magnitude of the force cause different target frames in the database. One is standing steadily with hands open, just as shown in Figure 8, one is standing with one step back, as shown in Figure9. Its final response motion generation is not the same as well.

FIGURE 8 Equilibrium holding remotion of reactiveness - Stretch to maintain a balance.

FIGURE 9 Equilibrium-maintaining motion of reactiveness - Back to maintain a balance.

4 Conclusion

This paper reviews mainstream technologies of motion capture data editing and does some researches respectively on the path synthesis as well as the interactive control and response motions generated by puppet animation and virtual characters. Innovativeness in this article includes:

(1) Mot1noGarph optimization and accelerated search Firstly we clustered jumping-points of Mot1noGarph which merges parts of the vertex, improves its structure and reduces the search space. Secondly, through the side labelling technology, path-matching calculation frame by frame is not required when does backtracking search. It greatly reduces the complexity of the search calculations; makes path synthesis of certain length can be achieved concurrently and facilitates users' interactive editing.

(2) Puppet animation simulation by using motion capture data. We established the physical model of puppet on the basis of its mechanical principle analysis. According to the specified target position from database of users, the theory of determining the drawing direction of the rope by solving the torque balance was proposed when doing puppet animation simulation. In addition, it gives a virtual smooth velocity curve for generating physical realistic animations.

In the taekwondo experiments, interactive control and response motion generation was achieved; concurrent response motion generation was proposing for offsetting the insufficiency of simply capture data.

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