From motion capture data to character animation

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Gaojin Wen
Chinese Academy of Sciences

Zhaoqi Wang
Chinese Academy of Sciences

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Gaojin Wen
Institute of Computing Technology
Chinese Academy of Sciences
Graduate school of the Chinese Academy of Sciences
100080, Beijing, China
gjwen@ict.ac.cn

Zhaoqi Wang
Institute of Computing Technology
Chinese Academy of Sciences
100080, Beijing, China
zqwang@ict.ac.cn

Shihong Xia
Institute of Computing Technology
Chinese Academy of Sciences
100080, Beijing, China
xsh@ict.ac.cn

Dengming Zhu
Institute of Computing Technology
Chinese Academy of Sciences
100080, Beijing, China
mdzhu@ict.ac.cn

ABSTRACT

In this paper, we propose a practical and systematical solution to the mapping problem that is from 3D marker position data recorded by optical motion capture systems to joint trajectories together with a matching skeleton based on least-squares fitting techniques. First, we preprocess the raw data and estimate the joint centers based on related efficient techniques. Second, a skeleton of fixed length which precisely matching the joint centers are generated by an articulated skeleton fitting method. Finally, we calculate and rectify joint angles with a minimum angle modification technique. We present the results for our approach as applied to several motion-capture behaviors, which demonstrates the positional accuracy and usefulness of our method.

Categories and Subject Descriptors

I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism —*Animation*; G.1.6 [**Numerical Analysis**]: Optimization—*Least squares methods*

General Terms

Algorithms

Keywords

motion capture, articulated skeleton fitting

1. INTRODUCTION

Motion capture has become an increasingly popular approach for character animation. It motivates many excellent work in related fields, which are focused on adapting captured data to new situations such as motion warping, motion filtering, motion retargetting and motion synthesizing. For most of those work a fixed length skeleton and joint angle plus root trajectories are used as input. This format requires an inherent mapping that is from the markers, moving in Cartesian 3D-space, to a fixed length skeleton and a relative motion representation which is defined by joint angles plus a body center or root.

Most popular commercial software, used for processing motion capture data such as Autodesk's MotionBuilder [2] and Character Studio [1], generate the skeleton for skeleton animation mainly by elaborate handwork, which often leads to heavy dependence on the skills of the animators. Contrast to these tools, without manual modification, our method determines the length of the skeleton by optimization directly, which not only saves artists' time but also allows much simplification in skeleton generation.

Focused on this mapping problem, we present a practical and systematic method based on least-squares fitting techniques in this paper, and which results in a precise match between the raw motion capture data and the skeleton motion data and also can be used to the processing of magnetic motion capture data.

2. RELATED WORK

2.1 Data Processing

Several computer researchers has focused on the motion capture data preprocessing, which covers the marker segmentation [14, 9], marker correspondence [10, 9] and rigidity augmentation [16]. Under affine transformations, Baihua Li et al. proposed an efficient global hierachical search strategy to reconstruct articulated poses with sparse feature points and achieved some robustness to data noise, which was caused by missing/extra marker and segment distortion [10]. Based on the absolute orientation technique [8, 15], we presented an efficient total least squares fitting method to promote the rigidity of marker sets on some special segments such as waist and head in our previous work [16].

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2.2 Joint Estimation

Several methods for estimating the location of joint ter have been proposed and even applied to comme softwares, which focus on two classes of approaches: u anatomical landmarks with regression parameters or f tional analysis for the determination of the joint center. first class of methods typically positions markers onto actor according to anatomical features that related to definition of the Cartesian coordinate systems of the ments. Regression parameters are used as the coordin of the joint ,which is generated by regression analysis on atively small samples of isolated subjects such as estima of the hip joint [13]. This method has been widely usec its simplicity in realization and computation as is revie in [5], and a complete joint center computation metho this class can also be found in [5].

The second class of methods is due to the straigh ward knowledge that two adjacent body segments have point in common, that is the joint center [11, 12]. Base an equivalent knowledge that a given marker traces o sphere which centred at the joint center, Silaghi et al. a weighted average of the centres of rotation that give individual markers [14] as the joints. Adam et al. add small distance penalty to restrict the location of joints for optical motion capture data [9]. Cameron et al. presented a sequential fashion algorithm to locate the rotation centres of a human skeleton from marker data [3]. This method is closed-form, enabling realtime implementation.

2.3 Motion Capture

Some computer graphics researchers have explored various techniques for improving the motion capture pipeline based on optical [14, 6], magnetic [11] or video technique [7]. Silaghi et al. proposed a partially automatic method for cacualting skeletons from motion capture data [14] with substantial user interaction. Their system suffers from local minima and expensive computation cost. Zordan and Horst addressed the mapping problem and solved it based on an complicated physical model [17] and with some manual work in setting internal parameters. Davis and his colleagues gave a rapid character animation generation method by reconstructing possible 3D poses from 2D hand drawing in no more than ten key frames and interpolating the manually selected most likely 3D poses [7]. In order to ensure end-effector positional accuracy, Choi et al. applied inverse kinematics to selected key frames and then optimized the total motion with constraints for preserving the original motion pattern [6].

Different from the work mentioned above, we think that the positional accuracy of joint centers and end-effectors can mostly preserve the reality of the captured motions. For this goal, we propose an articulated skeleton fitting method and an angle rectification technique, which are easy for implementation and of high performance.

3. SYSTEM OVERVIEW

Our system, MotionModeling, comprises four independent modules (Figure 1), which are discussed in detail in the next four subsections.

3.1 Data Preprocessing

For successful application of the commercial optical motion capture equipments such as Vicon motion capture system, most of the raw motion capture data, as the input of our system, is of high quality. So we do not consider the marker segmentation and marker correspondence problems at present. There is still possibility that the 3D points of some frames may have been lost or of much noise.

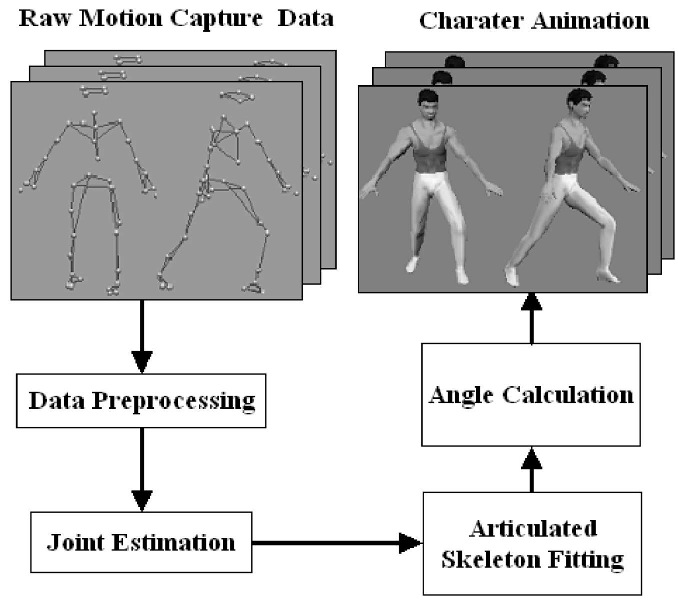


Figure 1: Module structure of our motion capture data processing system: MotionModelng.

For the loss of markers in some frames, we realize some simple operations such as cutting, interpolating and filtering based on the sufficiently mature signal processing techniques through an interactive curve editing panel.

During motion capture, more than three passive optical markers are placed on some segments of the actor such as the waist, head and radius. Ideally, the position and orientation of these segments can be determined by the markers on it. But unfortunately, these markers will move slightly due to the unintentional motion of skin or cloth of the actor. This is a segment distortion problem, which is equivalent to obtain the best position and orientation of the segment from several frames of the 3D marker data. We have proposed an efficient method for this problem [16].

3.2 Joint Estimation

In optical motion capture applications especially for character animation, two model marker sets have been widely used, which construct of 28 or 41 markers, in which each key joint or end, such as knee, ankle, toe, shoulder, elbow, hand, is placed with one marker, two markers are located on the wrist joints and four markers on the waist, chest and head. One auxiliary marker is placed on each segment of the leg and arm. The CMU graphics lab motion capture database used this marker set. The marker set of 28 markers is used in Character Studio [1], in which, the auxiliary markers (in the marker set of 41 markers) are eliminated. These markers should be attached to the actor with strict anatomical regularity [4]. We choose the first class of method to calculate the joints, as is suggested in [13, 5]. By this method, joints are efficiently calculated with regression parameters and experimental solutions.

3.3 Skeleton Fitting

In fact, the previously computed joints are instantaneous for each frames of raw motion capture data, and the constraint of fixed bone lengths is not considered. We will optimize these joints to satisfy the fixed-bone-length constraint with an articulated skeleton fitting technique which is described in the following subsections.

3.3.1 Articulated Skeleton Fitting

Our notation is as follows. The original locations of the joints of an articulated skeleton with M bones is $\mathbf{q}_{fj} = (x_{fj}, y_{fj}, z_{fj})$, where the subscript j $(0 < j < N)$ means the j-th joint of the skeleton, and the subscript f $(0 < f < F)$ means the f-th frame. The object 3D coordinates of a joint is $\mathbf{p}_{fj} = (\overline{x}_{fj}, \overline{y}_{fj}, \overline{z}_{fj})$. The length of the k-th bone which connects joints $\mathbf{q}_{fk^-}$ and $\mathbf{q}_{fk^+}$ is given by l_k,$(1 < k < M)$. We have the following equality-constrained optimization problem:

$$\min_{x,l} \quad \sum_{f=1}^{F}\sum_{j=1}^{N} \|\mathbf{p}_{fj} - \mathbf{q}_{fj}\|^2 \qquad (1)$$

$$s.t. \quad \|\mathbf{p}_{fk^+} - \mathbf{p}_{fk^-}\|^2 - l_k^2 = 0, \;\; 1 < k < M$$

The solution to the above problem can be obtained by Sequential Quadratic Programming (SQP) method, which works well for small scale problem $(F * N * 3 < 800)$. The Hessian matrix of this problem is a spare matrix, so it is natural to apply sparse matrix technique to save the computer memory and reduce the calculation complexity that are actually important when the problem becomes medium-scale problem $(F * N * 3 > 1000)$.

3.3.2 complexity reduction

As the number of the data frames grows, the performance of above solution method becomes timeconsuming. We Introduce two levels of feasible reduction:

Skeleton dividing. Substitute to optimizing all the locations of joints of the skeleton altogether, we divide the skeleton into five several links and optimize them link by link.

Fitting with know skeleton. Sometimes, we can obtain the skeleton length beforehand, e.g. obtained from measurement or from processing a calibration motion (Range of motion) then (1) becomes F small-scale equality-constrained optimization problems, which can be solved by Lagrange Multiplier method efficiently and ensure a high performance.

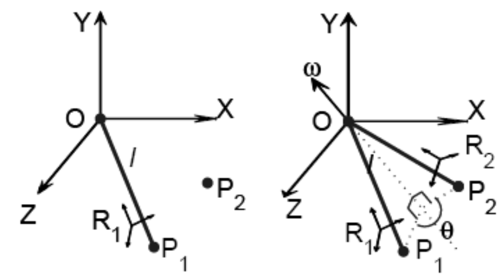
3.4 Angle Calculation

We can position and orient each segment using the information that obtained from the optimized skeleton and the 3D marker data. Then the joint angles can be computed from the coordinates of their adjoint segment. For example, the 3×3 orientation matrixes of if the i-th and the adjoint $(i+1)$-th bone are R_i and R_{i+1}, the angle of the joint connecting these two bones is the euler angle that generated from rotation matrix $R_i^{-1} R_{i+1}$.

3.4.1 Minimum Angle Rectification

The results of the previous angle calculation are spoiled by several sources of errors such as the muscle and skin deformation or simplified joint model, and errors will be accumulated along articulated skeleton from the base to the end-effector when the joint position is considered. We have to use some tricks to rectify the joint angles.

Actually, we are faced with such a problem, (see Figure 2(a)), with the joint angle v, we rotate the next bone $\boldsymbol{l}$ from a standard orientation to orientation R_1 , and the end of $\boldsymbol{l}$ reaches location P_1, which is usually some short distance from the optimized location P_2. How should we continue to rotate $\boldsymbol{l}$ to P_2 with the least modification on the orientation R_1?



(a) (b)

Figure 2: Minimum angle rectification problem.

Fortunately, we can generate the solution easily by knowledge of space geometry. See Figure 2(b), when ω parallels to the vector product of OP_1 and OP_2, θ reaches its minimum $\theta = 2\arcsin(\frac{\|P_1P_2\|}{2\|OP_1\|})$ and the least orientation modification condition is also satisfied at the same time.

4. EXAMPLES AND IMPLEMENTATION

We have implemented our system with visual c++.net and run it on a Pentium PC (single Pentium IV processor, 2.8GHz), see Figure 3. Some of the motion data described below are acquired by a Vicon 512 motion capture system operating at 120Hz. There were 12 cameras, mounted approximately 2.5m high encircling the 6m length $\times$ 6m width $\times$ 3m height capture volume for most of the data. In Figure 4, from left to right and from top to bottom, four images of walk illustrate the processing procedure of the optical motion capture data. Figure 5 shows two animation sequences created by our system, in which skinned characters are driven perfectly.

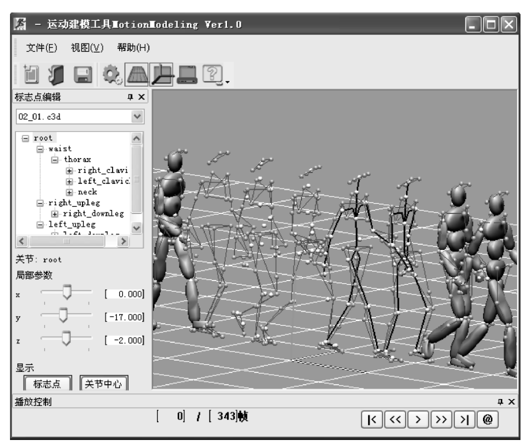


Figure 3: Interface of our MotionModeling system.

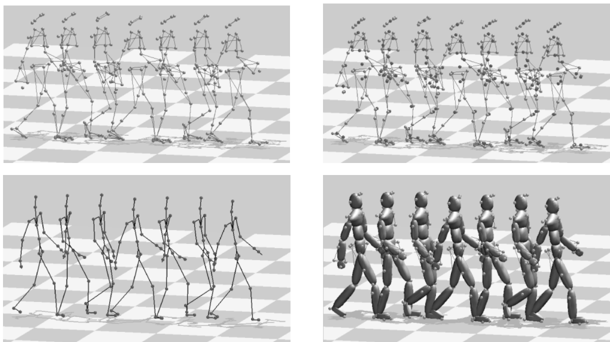


Figure 4: From left to right and from top to bottom, these four images of walk show the processing of optical motion capture data. Raw data is preprocessed to be of high quality in the left image of the top row, and joints, which are denoted as black balls in this figure, are estimated as in the right image of the top row. Then skeleton is optimized in the left image of bottom row. Finally, joint angles are calculated, rectified and applied to animate character in the right image of the bottom row.

5. CONCLUSIONS

In this paper, we have presented a systematic method for the processing of motion capture data. It can obtain the optimized skeleton with fixed length and rectified joint angles that precisely matching the raw motion capture data. At the same time, it achieves the positional accuracy of the joint centers and end-effectors, which help us to take full advantage of the subtle details of motion that are offered by motion capture techniques and far beyond the keyframe animation. In several examples of motion capture data processing, we have demonstrated the usefulness of the method.

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7. REFERENCES

[1] Autodesk. Character studio. http://www.autodesk.com.
[2] Autodesk. Motionbuilder. http://www.autodesk.com.
[3] J. Cameron and J. Lasenby. A real-time sequential algorithm for human joint localization. In *Proc. SIGGRAPH '05*, 2005. posters(111).
[4] E. T. Center. Marker placement guide. Carnegie Mellon University, 2005. http://www.etc.cmu.edu/projects/mastermotion/Documents/markerPlacementGuide.doc.
[5] P. Cerveri, A. Pedotti, and G. Ferrigno. Robust recovery of human motion from video using kalman filters and virtual humans. *Hun Mov Sci*, 22(3):377–404, 2003.
[6] K.-J. Choi, S.-H. Park, and H.-S. Ko. Processing motion capture data to achieve positional accuracy. *Graphical Models and Image*, 61(5):260–273, September 1999.
[7] J. Davis, M. Agrawala, E. Chuang, Z. Popovic, and D. Salesin. A sketching interface for acticulated figure animation. In *Proc. Eurographics/SIGGRAPH Symposium on Computer animation '03*, pages 320–328, 2003.

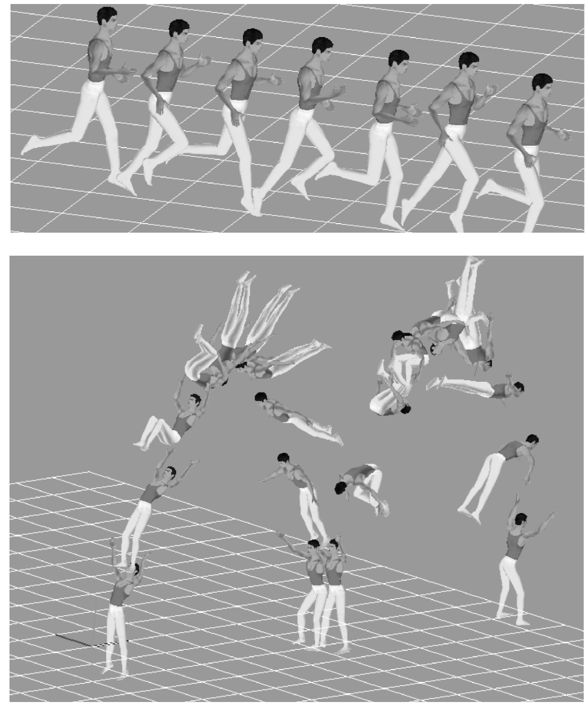

Figure 5: Skinny character animation generated by our system. Top image: run. Bottom image: trampoline. For the convenience of demonstration, we add an translation constant to every frame of this trampoline data.

[8] B. K. Horn. Closed-form solution of absolute orientation using unit quaternions. *J. Optical Society of America A*, 4(4):629–642, 1987.
[9] A. G. Kirk, J. F. O'Brien, and D. A. Forsyth. Skeletal parameter estimation from optical motion capture data. In *IEEE Conf. on Computer Vision and Pattern Recognition (2)*, pages 782–788, 2005.
[10] B. Li, Q. Meng, and H. Holstein. Articulated pose identification with sparse point features. *IEEE Trans. Systems, Man and Cybernetics*, 34(3):1412–1422, 2004.
[11] J. F. O'Brien, B. E. Bodenheimer, G. J. Brostow, and J. K. Hodgins. Automatic joint parameter estimation from magnetic motion capture data. In *Proc. Graphics Interface '00*, pages 53–60, 2000.
[12] M. H. Schwartz and A. Rozumalski. A new method for estimating joint parameters from motion data. *J. Biomechanics*, 38(1):107–116, 2005.
[13] G. K. Seidel, D. M. Marchinda, M. Dijkers, and R. W. S. Little. Hip joint center location from palpable bony landmarks a cadaver study. *J. Biomechanics*, 28(8):995–998, 1995.
[14] M.-C. Silaghi, R. Plankers, R. Boulic, P. Fua, and D. Thalmann. Local and global skeleton fitting techniques for optical motion capture. *Lecture Notes in Computer Science*, 1537:26–40, 1998.
[15] S. Umeyama. Least-squares estimation of transformation parameters between two point patterns. *IEEE Trans. Pattern Anal. Mach. Intell.*, 13(4):376–380, 1991.
[16] G. Wen, Z. Wang D. Zhu, and S. Xia. Least-squares fitting of multiple M-dimensional point sets. *The Visual Computer*, 22(6):387-398, 2006.
[17] V. B. Zordan and N. C. V. D. Horst. Mapping optical motion capture data to skeletal motion using a physical model. In *Proc. Eurographics/SIGGRAPH Symposium on Computer animation '03*, pages 245–250, 2003.