A Hybrid Motion Data Manipulation: Wavelet Based Motion Processing and Spacetime Rectification

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Abstract. In this paper, we present a hybrid approach to motion data manipulation. Motion signal is decomposed into multi-resolution levels with wavelet analysis. The coarse level represents the globe pattern of a motion signal while the fine levels describe the individual styles. Special motion style can be highlighted through enhancing the corresponding level content and can be fused into other motions by texturing them with related fine levels. And multiple motions can be synthesized by multi-resolution blending to create new motions somehow like to the blended motions. Motion signals implicitly preserve constraints to keep realistic. However, the above manipulations may inviolate some constraints and result in the unrealistic artifact. Spacetime rectification is proposed to reserve the essential constraints. Our experiment shows the effectiveness of this hybrid motion data manipulation approach.

1 Introduction

Recently, the increasing demand for powerful and intuitive animation systems has led to the development of new techniques. The motion capture system [1] provides tools for real-time animation, with extremely realistic results: human motion is captured and mapped onto animated characters, and the generated animation preserves the unique characteristic of the actor.

However, problems appear when we modify the captured data. Even if the modification is trifling, the whole motion capture procedure should be repeated. The powerful motion editing systems are demanded. These systems should provide easy and effective tools to modify motion data, including interactive editing, blending, stitching, smoothing and so on.

The goal of this research is to provide an efficient approach to motion editing. The motion signal is firstly decomposed into many resolution levels. The special motion feature can be highlighted through enhancing related level contents. And motions can be characterized with special styles by texturing them with corresponding fine levels. Also multiple motion signals can be synthesized by multi-resolution blending to create a series of new motions somehow like to the blended components. At last, spacetime

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rectification is proposed to preserve the essential constraints hidden in original motion signals to guarantee the resulting motion be realistic.

The remainder of this paper is organized as follows: in the following section, we will give a review on motion editing techniques. In Section 3, we describe wavelet analysis based motion manipulation methods in detail, including motion enhancement, motion style texturing and multiple motion synthesis. In Section 4, we elaborate spacetime motion rectification. And we show the experimental result in Section 5 and conclude the paper in the last section.

2 Related Work

Gleicher [2] suggested a constraint base method for editing a pre-existing motion such that it meets new needs yet preserves the original quality as much as possible. A similar technique for adapting an animated motion from one character to another was also suggested [3]. J.Lee [4] proposed a hierarchical approach to interactive motion editing. Popovic and Witkin [5] presented a physically based motion editing algorithm, which considers some physical attributes as constrains, besides those specified by users; meanwhile, to improve the efficiency of computation, it first handles the reduced motion model and then deals with the complete one.

Bruderlin and Williams [6] apply techniques from image and signal-processing domain to designing, modifying and adapting animated motion. Witkin and Popovic [7] introduced the idea of motion warping. Brand and Hertzmann [8] proposed a style machine, which produces new motion containing the desired feature by learning motion patterns from a highly varied set of motion capture sequences.

More recently, Lee [9] developed a multiresolution analysis method that guarantees coordinate invariance for use in motion editing operations. Pullen and Bregler[10] presented a motion capture assisted animation, which allows animators to keyframe motion for a subset of degrees of freedom of a character and use motion capture data to synthesize motion for the missing degrees of freedom and add texture to those keyframed. In the work of Li et al [11], motion data was divided into motion textons, each of which could be modeled by a linear dynamic system. Motions were synthesized by considering the likelihood of switching from one texton to the next.

3 Wavelet Based Motion Analysis and Manipulation

The posture of an articulate figure can be specified by its joint configurations together with the orientation and position of Root [12]. And motion can be regarded as a posture sequence. Using the multiresolution property of wavelet, motion signal S can be decomposed into many resolution levels as follows:

$$S = A_J + \sum_{j=1}^{J} D_j \, , J \in Z \, . \tag{1}$$

where A_J is the approximation, and D_j is the detail at level j. A_J conveys the overall trend of a motion, while D_js represent the mode, style and even the emotional contents of a motion.

3.1 Motion Enhancement

The coarse content of motion represents the main pattern and the fine contents correspond to some special motion styles. With the information at some resolution levels processed, the corresponding feature of a motion can be highlighted or weakened. For example, with high resolution contents enhanced, the corresponding details of motion can be highlighted. Whereas the transformation of low resolution content will change the basic attributes of a motion. In contrary to the Fourier transform in which the variations affect all the motion (as it is local only in frequency domain but not in time domain), the wavelet transform is local both in time and frequency domain. So editing a special part of the motion is possible without destroying the other parts. The main steps of motion enhancement algorithm are outlined below:

1) Apply discrete wavelet transform (DTW) to motion signal S_0 to decompose it into the coarse and fine coefficients and then apply inverse discrete wavelet transform (IDTW) to get the approximation and a series of details as Equation 1.
2) Enhance each component with multiple factors, and get the approximation and details of new motion signal S_n.
3) Reconstruct the new motion signal S_n as Equation 1.

Given a normal walk, we can modify the step size through adjusting the approximation of the original motion signals of joint Hip and Knee and edit arm motions through adjusting the approximation of the original motion of joint Shoulder analogously (See Fig. 3(a)). Moreover, enhancing the details of the motion of joint Knee, the quiver in the walk can be highlighted and thus a jittering walk is produced (See Fig. 3(b)).

3.2 Motion Style Texture

The approximation of a motion signal represents the overall trend, while the detailed parts indicate the individual styles. Texturing a given approximation with different detailed parts from other motions, a family of motion somehow like to each other is produced.

Motion synchronization processing is conducted beforehand. For example, to texturing a run motion with the style of a sexy walk, they must be in phase. Here we employ the motion time warping algorithm to align the original motions as follows:

$$f(t) = g(h(t)). \tag{2}$$

Where $h(t)$ is the time warping function, usually a linear subsection function, and $g(t)$,$f(t)$ are the motion before and after warping. Given two motions, the animator takes one as the reference and specifies several temporal corresponding points to determine $h(t)$.Then warp another motion as Equation 2, and the resulting motion is in phase with the reference one (See Fig. 1).

Due to the discrete expression of motion signal, two cases must be handled in performing re-sampling. When $h'(t)$ is less than 1, we must be able to determine what happens in between the individual samples. Otherwise, we must handle properly when throwing away information, since we will have fewer samples with which to encode things, and the problem called *alias* will occur. The former case can be easily handled by interpolation. For the latter, another motion can be selected as the reference to decrease $h'(t)$.

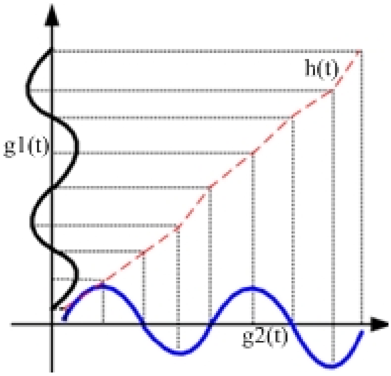

Fig. 1. Motion time warping. Taking *g2(t)* as the reference, the time warping function *h(t)* can be determined. Let *f(t)=g1(h(t))*, *f(t)* and *g2(t)* are synchronized

We describe the motion style texturing algorithm in the following steps:

1) Choose a dominating motion S_d, and a texture motion S_t.
2) Synchronize motions through motion time warping.
3) Apply DTW to the dominating motion signal S_d to decompose it into the coarse and detail coefficients and then apply IDTW to get the approximation A_{dJ} and a series of details $D_{di.}$ Similarly, $D_{ti,}$ the detailed parts of the texture motion S_t, can be extracted.
4) Texture the approximation A_{dJ} with the detailed parts D_{tj} and $D_{dj.}$ Let S_n be the resulting motion signal, w_j be the texturing weight of detailed part *j*, the resulting motion signal S_n can be reconstructed as follows:

$$S_n = A_{dJ} + \sum_{j=1}^{J} w_j D_{tj} + (1 - w_j) D_{dj}, J \in Z . \tag{3}$$

3.3 Motion Synthesis

Motion blending is a useful operation, in which multiple motions are interpolated to create a motion family somehow like to the blended ones. Using the multiresolution property of wavelet analysis, we can perform blending at different resolution levels using different blending operators. For extrapolation among motions is unsuitable here, the empirical blending operators is between -0.5 and 1.5. Since wavelet transform is local both in time and frequency domain, each blending operation is independent.

The main steps of the multiresolution blending operation are outlined below:

1) Synchronize the blended motions using motion time warping algorithm.
2) Apply DTW to the blended motion signal S_i to decompose it into the coarse and detail coefficients and then apply IDTW to get the approximation A_{iJ} and a series of details D_{ij}.
3) Blend motions independently at each resolution level with rational operators and get the approximation and details of the new motion.

4) Reconstruct the resulting motion signal S_n as Equation 1.

Applying the above algorithm to blend a sneaking walk and a normal run, we can obtain a sneaking run shown as Fig. 4.

4 Spacetime Constrained Based Motion Rectification

The above motion data manipulations provide an easy and effective tool for motion editing. However, it can not guarantee the resulting motion to be realistic. This is because editing on a motion may inviolate the constraints hidden in the motion data and thus destroy the harmony and physical correction. The constraints mainly focus on the following two points:

1) The postures should be physical correct.
2) The transformation between postures should be rational.

These are spatial and temporal constraints. To make up the damaged, essential spacetime constraints [2] can be imposed on motion data. Then establish objective functions to prescribe how to accomplish the resulting motion. At last, solve the constraint optimization problem for the rectified motions. The main step of the motion rectification algorithm is outlined below:

1) Impose formulized spacetime constraints on motion signals;
2) Establish objective functions;
3) Solve the constraint optimization problems using inverse kinematics and numerical optimization methods.

Spacetime constraints are special spatial and temporal restrictions on motion, aiming at preserving essential properties of motions while meeting new requirements. For example, to avoid the body's slipping we prescribe that a foot touch the ground while walking. Both kinematics and dynamics attributes of motion can serve as constraints. However, kinematical constraints are the preference due to the complexity of dynamics. Those constraints are usually specified during a period of time and they can be decomposed into the discrete kinematical constraints on individual frames through sampling. We satisfy the constraints on each frame so as to meet the constraints over the whole period of motions.

Objective functions aim at how to accomplish a motion. In resolving the continuous motion, after specifying objective functions for character movement, the system is able to select the exclusive solution from a set of reasonable ones. Considering different parameters often have vastly different effects, we adopt a weighted sum-of-squares of the parameters. The objective can be seen as an approximation to the function that minimizes the difference from ideal position. The following two measurements can serve as objective functions:

1) Minimizing the difference of position between ideal joints and practical joints;
2) Minimizing the difference of movement before and after motion edition.

Both forward and inverse kinematics can be employed to solve the problem of spacetime constraints optimization. Using forward kinematics, animators need to specify the values of all motion parameters directly to move a character, while inverse kinematics (IK) allows moving the position or orientation handles attached to points

(a) Walk before rectification (b) Walk after rectification

Fig. 2. Motion rectification

on a character's body and lets the computer figure out how to set the joint angles to achieve the goals. Inverse kinematics can relieve the heavy work of animators in contrary to forward kinematics degree. We combine IK with numerical optimization methods to improve the computational efficiency.

4.1 Sample

When we enhance or weaken the approximation of a walk motion, and create new motions with various steps (See Section 3.1), the unexpected problem occurs:

1) Sometimes the foot gets into the ground, for example frame 9, 11, 13 in Fig.2 (a); and sometimes the foot hangs in the air, as frame 1, 3, 17 shown in Fig.2 (a).
2) Slipping occurs during walking with big steps.

The violation against that at least one foot should contact the ground during walking, causes the above problem 1) and the violation against that the location of the foot contacting the ground remain unchangeable results in the problem 2). So we restrict that the foot contact the ground during walking, and remain still during half cycle of motion. And these are imposed on motion as spacetime constraints. And we define the objective function on minimizing the difference of movement before and after motion editing. Solve this constraint optimization problem and we get the rectified motion shown in Fig.2 (b).

5 Result

We devise an equalizer based on motion enhancement algorithm to aid animators to edit motions. Given a normal walking motion(See Fig. 3(c)), we enhance the approximations of the motion of joint Hip, Knee and Shoulder, and create a new walking with large steps shown in Fig. 3(d). And if the details of motion signals are enhanced, jittering in the motion is highlighted (See Fig. 3(e)). (All the resulting motions shown have been rectified using the method in Section 4).

The style of a sexy walk is embodied mainly by the twisting of joint Hip. We select a run as the dominating motion and extract its approximation. Then texture it with the details of the motion signal of joint Hip from a sexy walk and create a sexy running motion (See Fig. 5(b)). Also we can texture it with details from other motions and characterize it with corresponding styles shown in Fig. 5(d).

If multiple motions are synthesized by multiresolution blending, new motions somehow like to the blended are created. For example, if we blend a running motion with a series of walking motions with different style respectively, corresponding new motions are synthesized (See Fig. 4).

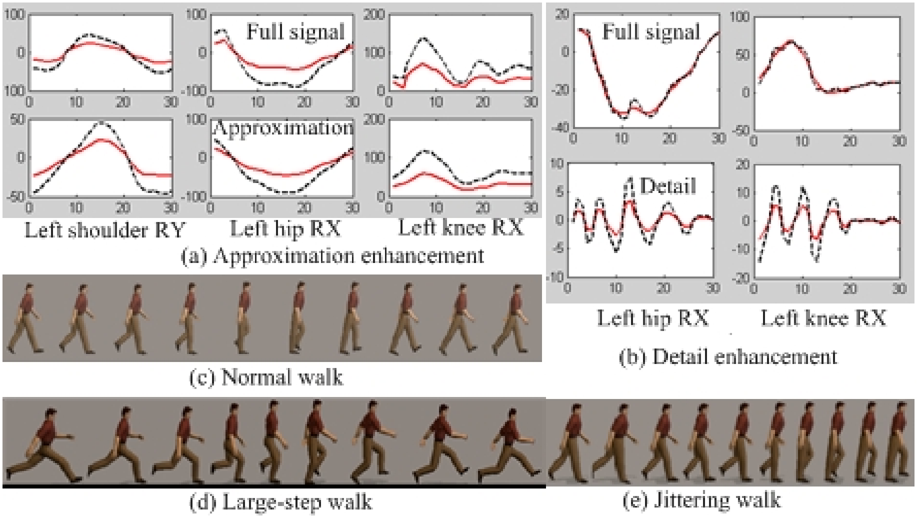

Fig. 3. Motion enhancement. The solid line represents the input signal and the dashed line is the output signal

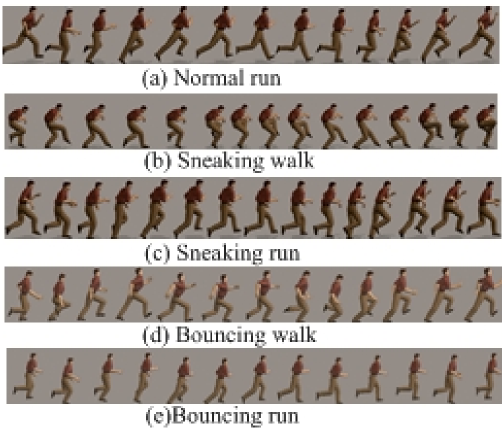

Fig. 4. Motion synthesis

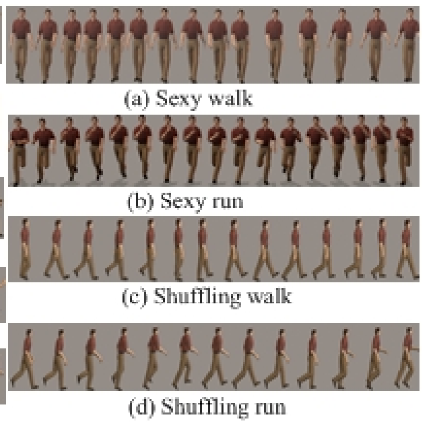

Fig. 5. Motion texturing

6 Conclusion

Motion editing is the key technique to improve the reusability of motion capture data. The goal of this research is to provide an easy and effective tool to adapt the pre-existing motion data to new application. Using the powerful multiresolution property, we decompose the motion signals into many resolution levels, and get the approximation and details. Unlike the Fourier transform, the wavelet transform is local both in time and frequency domain, we can manipulate the contents at each resolution levels independently. We propose some useful approaches to motion editing, including motion enhancement, motion style texturing and motion synthesis by blending. Considering that the above manipulation may inviolate the constraints which guarantee the reality of motions, we introduce spacetime constraints to resume the damaged property of motions. Using inverse kinematics and numerical methods, we can solve the constraint optimization problems for the rectified motions.

However, human motion is a harmonious combination of motions of all the joints. The modification on partial joints' motions will destroy the harmony. And it is difficult to formulize the harmony hidden among the raw motion data. Our future work will focus on it.

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References

1. Xiaoming Liu, Yueting Zhuang, Yunhe Pan. Video Based Human Animation Technique. ACM Multimedia'99 10/99 Orlando, FL, USA, pages 353-362, 1999.
2. Michael Gleicher. Motion editing with spacetime constraints. In Michael Cohenand David Zeltzer, editors, 1997 Symposium on Interactive 3D Graphics, pages139–148. ACM SIGGRAPH, April 1997.
3. M.Gleicher. Retargeting motion to new characters. Computer Graphics (Proceedings of SIGGRAPH 98), 32:33-42, July 1998.
4. Jehee Lee and Sung Yong Shin. A hierarchical approach to interactive motion editing for human-like figures. Proceedings of SIGGRAPH 99, pages 39-48, August 1999.
5. Zoran Popovic and Andrew Witkin. Physically based motion transformation. Computer Graphics (Proceedings of SIGGRAPH 99, Los Angeles, August 8-13, 1999).
6. A. Bruderlin and L. Williams. Motion signal processing. Computer Graphics (Proceedings of SIGGRAPH 95), 29:97–104, August 1995.
7. A. Witkin and Z. Popovic. Motion warping. Computer Graphics (Proceedings of SIGGRAPH 95), 29:105–108, August, 1995.
8. Matthew Brand and Aaron Hertzmann. Style Machine. In Proceedings of SIGGRAPH 2000, July 23-28, 2000. New Orleans, Louisiana, USA.
9. Jehee Lee and Sung Yong Shin, Multiresolution Motion Analysis with Applications, *The international workshop on Human Modeling and Animation*, Seoul, pp. 131-143, June 2000.
10. Pullen, K., and Bregler, C. 2002. Motion capture assisted animation: Texturing and synthesis. In *Proceedings of SIGGRAPH 2002*.
11. LI, Y., Wang, T., and Shum, H.-Y. 2002. Motion texture: A two-level statistical model for character synthesis. In *Proceedings of SIGGRAPH 2002*.
12. F. Sebastian Grassia, Motion Editing: Mathematical Foundations, in course: Motion Editing: Principles, Practice, and Promise, in Proceedings of SIGGRAPH 2000, July 23-28, 2000. New Orleans, Louisiana, USA