Watermarking Space Curves

Rakhi C. Motwani*, Mukesh C. Motwani*, Kostas E. Bekris*, and Frederick C. Harris, Jr.*
*Department of Computer Science and Engineering
University of Nevada, Reno USA 89507

***Abstract*—This paper describes an imperceptible, non-blind, fragile watermarking technique for space curves. The proposed technique employs a wavelet-based approach, and computes a multi-resolution representation of the space curve to embed a watermark so that it has widespread presence in the curve. A variety of wavelet families are exploited and experimental results provide a comparison of the performance of different wavelets in terms of the watermark's imperceptibility and tolerance to attacks. To quantify space curve distortion, a signal-to-noise ratio is used, and a linear correlation measure is employed to determine the resistance of the watermark to modifications.**

I. Introduction

Motion capture (MoCap) technology yields appealing computer graphics animations but entails high investments in terms of cost, time and effort. The digital nature of MoCap data makes it vulnerable to piracy and plagiarism, thereby discouraging MoCap studios and labs from publishing such data. This paper focuses on tamper detection in trajectories (space curves) derived from motion capture data, to assist in detecting modifications that violate copyrights of motion data extracted from published MoCap datasets.

Watermarking techniques have been used for copyright protection, ownership authentication, and tamper proofing of digital data. Watermarking schemes insert information in the digital content in such a way that the embedded information is imperceptible to the the human eye. Robust watermarking techniques strive to embed information in such a way that it is difficult to remove without causing perceivable distortions to the original data. However, this is a challenging research problem therefore such schemes are only tolerant to a limited set of attacks. Fragile watermarking schemes, on the other hand, embed watermarks that have low resistance to modifications and are destroyed at the slightest variation to the host content. Therefore, fragile schemes find applications in tamper proofing digital data, since a damaged watermark signals a malicious modification attempt to the data.

Research related to watermarking of 3D data is still in its infancy, and finds applications to 3D meshes and motion data streams. The rest of this paper is organized as follows. Section II presents the related work in this relatively immature field. Section III describes the proposed watermarking approach. Section IV provides the results of experiments. Conclusions with future work are summed up in Section V.

II. Related Work

Related work on curve watermarking has been investigated for planar curves (in the 2D contex) for copyright protection of digitally distributed maps ([1], [2], [3]), vector fonts [4], hand drawn curves and topographic maps [5]. However, limited work has been done on curve/trajectory/motion-data watermarking in the 3D domain.

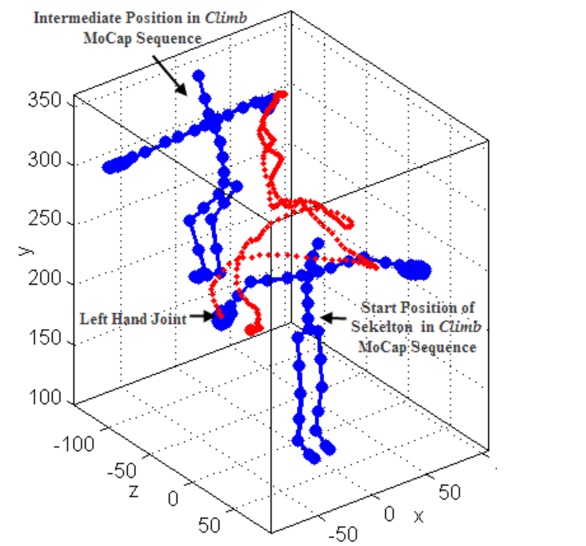

Fig. 1. Trajectory Plot(red) of Left Hand Joint of Human Skeleton(blue). Motion Sequence from *climb.bvh*

The authors in [6] propose a progressive watermarking scheme for 3D motion capture data that uses frame decimation. A robust, blind 3D motion capture data watermarking algorithm for human motion animation is proposed in [7], that is cluster-based and uses quantization techniques. The authors in [8], describe a spatial domain technique to watermark 3D motion capture data. Pu *et al.* [9], adopt singular value decomposition to consider both the time varying relations among the motion frames and the spatial correlations among the different joints in motion. The motion data matrix is decomposed into two eigen vector matrices and a singular values matrix. The watermark is added to the singular values matrix. Agarwal and Prabhakaran [10] propose a tamper-proofing mechanism for MoCap data that applies hash functions to the data matrix and embed identifiers as watermarks to detect attacks such as row/column shuffling and element shuffling.

Most watermarking techniques [11] adopt a certain level of randomness in the algorithm to battle attacks on watermark removal by brute force approach. However, this is the simplest approach and has its drawbacks. Embedding the watermark directly in the spatial domain makes it vulnerable to removal or replacement attacks. It is preferred to transform the motion data into frequency domain. This assures that the watermark is spread across the 3D curve such that removal or replacement of parts of the curve does not destroy the watermark completely. In [12], Yamazaki proposes segmentation of the motion data followed by a discrete cosine transform operation on each segment to embed the watermark in the spread spectrum domain. In [13], Yamazaki employs wavelet-based spectral analysis for watermark insertion. The watermarking approach presented in this paper also employs wavelets but differs from Yamazaki's approach as it utilizes a multiresolution wavelet representation of the 3D curve for watermark insertion. Moreover, the proposed approach isolates the trajectories of the human skeletal joints and applies to the space curve generated by each joint. In addition, a variety of wavelet families are experimented with to determine the best performer.

III. Methodology

For MoCap data, a space curve is a sequence of coordinates in 3D space. This space curve is derived from the motion of one joint (denoted by dot marker) of the human skeleton, as shown in Fig. 1. The MoCap dataset used for this figure is obtained from *BeyondMotion Studio* [14] and represents the *climb.bvh* sequence. The space curve is the trajectory represented by red markers in the plot below.

The proposed approach transforms the spatial representation of the 3D curve to the spread spectrum domain using wavelets [15]. Wavelet transform is preferred over Fourier or Discrete Cosine transforms because it captures both the global pattern (i.e. averages or approximations) and the local variations (i.e. fluctuations or details) in the curve. Wavelet functions decompose a space curve into multiple resolutions thereby facilitating examination of the gross and finer details of the curve at different scales or resolutions. The following subsections describe the the proposed multiresolution wavelet-based, non-blind watermarking approach.

A. MultiResolution Analysis

The space curve is represented by a three-dimensional discrete signal C of length n. The wavelet transform is applied to the x, y and z co-ordinates of C separately. As depicted by Eq. 1, a discrete wavelet transform applied to C decomposes the signal into two sub-signals, S_i and W_i, of half its length ($m = \frac{n}{2}$ where n is an integral power of 2 with zero padding), where i represents the multiresolution level of wavelet transform.

$$C[n] = S_i[m] + W_i[m] \tag{1}$$

The first sub-signal constitutes the scalar co-efficients that represent the approximation of the original signal and is computed by the following equation:

$$S_i = \sum_k C(k)\phi_i(k) \tag{2}$$

where $\phi(k)$ represents the scaling function of the chosen wavelet family.

The second sub-signal represents the wavelet co-efficients that constitute the differences between the subsequent components of the original signal and is denoted by:

$$W_i = \sum_k C(k)\varphi_i(k) \tag{3}$$

where $\varphi(k)$ represents the wavelt function of the chosen wavelet family. The functions $\phi(k)$ and $\varphi(k)$ are defined by the chosen wavelet. *Haar, Daubechies, Biorthogonal, Meyer,* and *Mexican Hat* are different families of wavelets. Readers are advised to refer to [16], [17], and [18] for further details on wavelet transform.

A multi-resolution representation of the space curve decomposed at levels with decreasing resolution, is demonstrated in Fig. 2. A visual representation of multiresolution wavelet decomposition of C into approximation and detail co-efficients, in the x-dimension, is shown in Fig. 3.

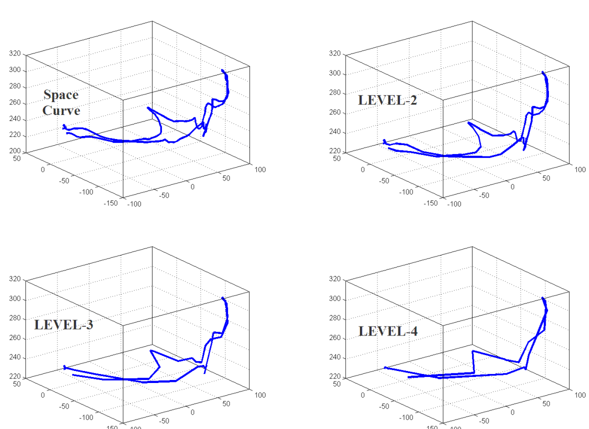

Fig. 2. Multiresolution Analysis of the Space Curve- The space curve is represented at decreasing scales (Level-2 wavelet transform yields a higher scale, Level 4 results in a lower scale). The finer details are lost by lowering the resolution.

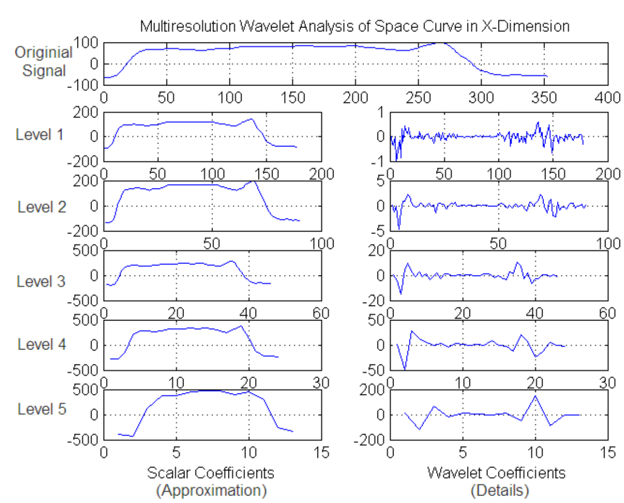

Fig. 3. Original Signal in x-dimension and its Multiresolution Wavelet Decomposition at Levels 1 through 5

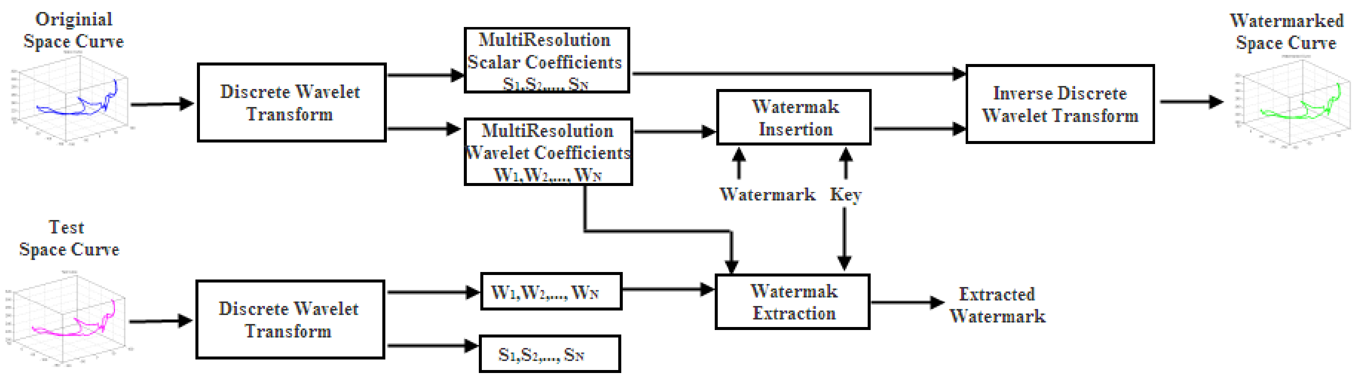

Fig. 4. Watermark Insertion and Extraction Process

B. Watermark Embedding

The steps underlying the process of watermark insertion and extraction are demonstrated by Fig. 4. The watermark insertion process adds a random watermark R_j to the multiresolution wavelet coefficients W_j selected by a key K_j, which is derived from a pseudo-random number generator function, where j represents the x, y, z dimension. The watermark R is a sequence of pseudo-random numbers. The watermark is multiplied by a scaling factor M, which determines the embedding strength. Experimental values for M lie in the range 10^{-4} to 10^{-5}.

The watermark is inserted into the multiresolution wavelet coefficients according to the following equation:

$$W_j^{'}(k) = W_j(k) + R_j M \tag{4}$$

where $W^{'}$ denotes the watermarked wavelet coefficient, k denotes the wavelet coefficient's index selected by key K_j, and j represents the x, y and z coordinates of the space curve.

Inverse transform applied to the unmodified scalar coefficients and the modified wavelet coefficients yields the watermarked space curve as shown in Fig. 5. The space curve in this figure represents the trajectory generated by red markers plotted in Fig. 1, but it looks different since it has been plotted independently of the skeleton with the x,y,z axes swapped and does not incorporate the scaling of the coordinate axes in the plot.

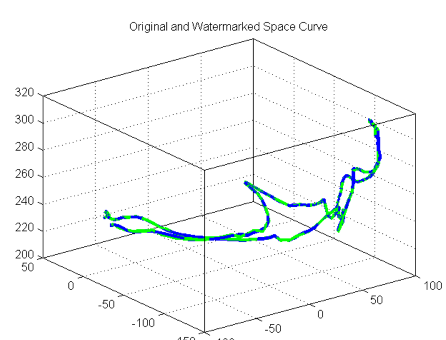

Fig. 5. Original(blue) and Watermarked(green) Space Curves

C. Watermark Detection

To detect if a space curve has been modified, wavelet domain representation of the original 3D curve is subtracted from the wavelet domain representation of the test space curve. The extraction process requires the key K, hence the watermarking technique is non-blind. Correlation of the subtraction result with the original watermark determines if the curve has been tampered with or not.

A linear correlation coefficient $corr$ is used as the metric for similarity between the original and extracted watermark. Given pairs of quantities (i.e. two sets of data A and B) (A_j, B_j), where $j = 1, \ldots, N$ and $\bar{A}$ is the mean of all A_j's and $\bar{B}$ is the mean of all B_j's, $corr$ is given by the formula:

$$corr = \frac{\sum_j \left(A_j - \bar{A}\right)\left(B_j - \bar{B}\right)}{\sqrt{\sum_j \left(A_j - \bar{A}\right)^2}\sqrt{\sum_j \left(B_j - \bar{B}\right)^2}} \tag{5}$$

When $corr = 1$, the extracted watermark is identical to the original watermark, which implies that the test curve has not been tampered with.

IV. Experiments

The experiments ae done in Matlab using the Wavelet toolbox and Motion Capture toolbox [19]. The data used in this project is obtained from [20]. Distortion analysis of the original and watermarked space curves is based on the signal-to-noise ratio (SNR) metric which is given by the following equation:

$$SNR(C, C^{'}) = 20 Log_{10}\left(\frac{RMS(C)}{RMS(C - C')}\right) \tag{6}$$

where C is the original space curve and $C^{'}$ represents the watermarked space curve. RMS denotes the root-mean-square value. The imperceptibility of the watermarking algorithm is measured by this SNR value.

Results for distortion analysis for the space curve, shown in Fig. 6 (defined by 352 points in 3D), are listed in Table I. Experiments are conducted on a seven families of wavelets to determine the best performers. The payload value in Table I represents the length of the watermark (i.e. the number of

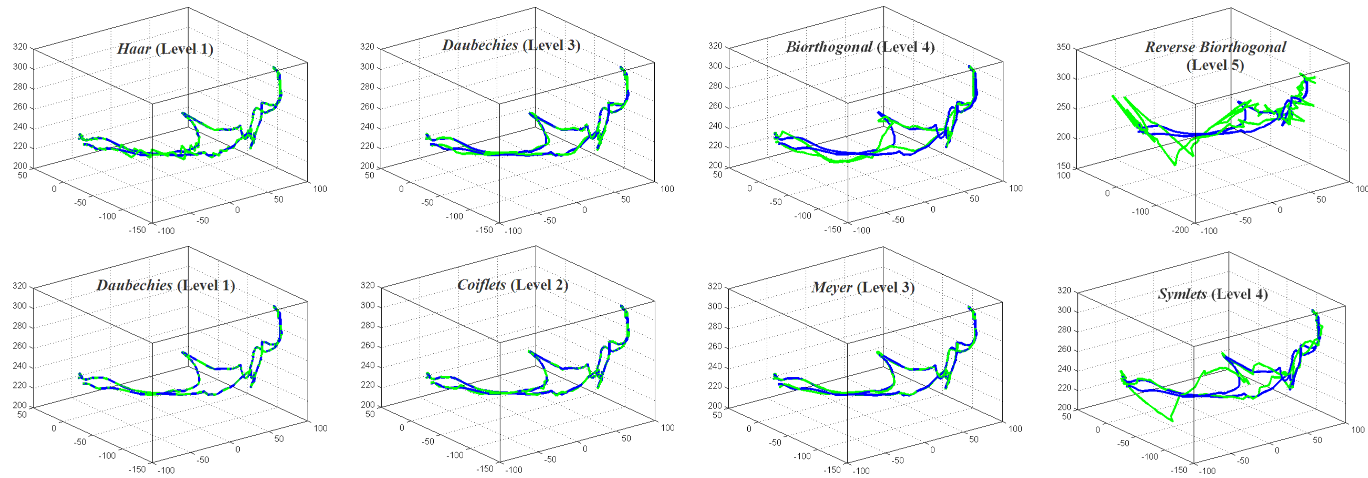

Fig. 6. Distortion Analysis-Original Space Curve(blue) and Watermarked Space Curve(green) at Different Levels of Transform for Different Wavelet Families

wavelet coefficients that are modified to accommodate the watermark). The payload capacity increases as the level of wavelet transform increases since the watermark is inserted into the wavelet coefficients from all levels 1 through N, where N is the level of applied wavelet transform. For example, SNR at Level-3 for *Haar* wavelet indicates presence of watermark in all Levels 1,2 and 3. Thus, SNR in Table I decreases as number of levels of the wavelet transform increases, since noise(watermark) is added at more levels. As depicted by Fig. 6, a visual distortion is observed in the watermarked space curve for SNR values lower than 50.

Payload	113	160	194	218	236
Wavelet Family	**Level-1**	**Level-2**	**Level-3**	**Level-4**	**Level-5**
Haar SNR	50.1264	42.0223	35.7126	30.2582	25.0681
Daubechies SNR	70.2424	59.8253	49.0849	38.5224	28.7898
Biorthogonal SNR	66.0393	56.8886	48.9948	36.6137	28.5002
Reverse Biorthogonal SNR	59.6760	48.9117	38.6306	29.8878	28.2937
Coiflets SNR	63.8576	53.9897	45.3761	34.2555	26.4873
Symlets SNR	64.2491	53.0709	44.6761	33.9973	29.5184
Meyer SNR	69.4834	61.8976	51.2509	39.6161	28.6246

TABLE I
IMPERCEPTIBILITY MEASURE AND PAYLOAD CAPACITY OF THE WATERMARKING ALGORITHM AT DIFFERENT LEVELS OF WAVELET TRANSFORM FOR A SPACE CURVE COMPRISED OF 352 POINTS

Results for various attacks on the watermarked space curve are shown in Fig. 7 and outlined in Table II. The correlation measure $corr$ determines the performance of the algorithm under the following attacks: i) cropping - in this attack parts of the space curve are removed by an adversary, ii) replacement - this attack involves modification of sections of the space curve by different data, and iii) concatenation - this attack appends data from different space curves to yield a new space curve.

Since the proposed watermarking scheme is fragile, the watermark is destroyed at the slightest variation to the space curve caused by attacks. When $corr$ is not equal to 1, it signals a modification to the watermarked space curve thereby indicating violation of copyrights. A $corr$ value of 1 indicates proof of ownership.

Wavelet Family	Crop	Replacement	Concatenation
Haar	0.3781	0.3129	1.0000
Daubechies	0.4273	0.6741	1.0000
Biorthogonal	0.3618	0.5392	1.0000
Reverse Biorthogonal	0.2346	0.4075	1.0000
Coiflets	0.3351	0.5813	1.0000
Symlets	0.3468	0.4927	1.0000
Meyer	0.3687	0.5360	1.0000

TABLE II
CORRELATION MEASURE FOR ATTACKS

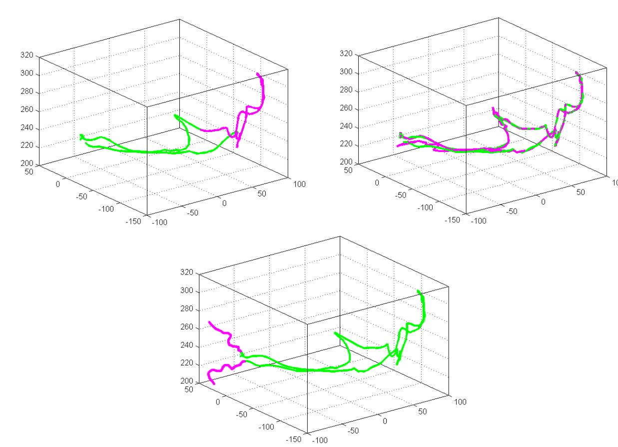

Fig. 7. Attacks(magenta) on Watermarked Space Curve(green): Cropping(Top Left), Replacement(Top Right), and Concatenation(Bottom)

V. Conclusions And Future work

This paper presents an imperceptible, fragile, non-blind watermarking technique for space curves derived from motion capture data. The proposed watermarking algorithm is based on multiresolution wavelet analysis of the space curve. The implementation embeds information into the wavelet coefficients to minimize perceivable distortion to the space curve since the human eye can not perceive changes in the higher frequencies. The algorithm maximizes the presence of the watermark across the entire space curve by modifying the wavelet coefficients at multiple resolution levels. The performance of various wavelet families at different levels of transform has been evaluated and experimental results indicate that the *Daubechies*, *Biorthogonal*, and *Meyer* wavelets yield better SNR and provide optimal performance at Level-3. Space curves with sharp discontinuities can be efficiently represented with *Haar* wavelet. Motion curves do not exhibit such abruptness and therefore the experiments have demonstrated improved performance using smoother wavelets. Future work entails varying the scaling factor M in accordance with the transform level of the wavelet coefficients.

Watermarking of space curves can only provide copyright protection for MoCap data. Protecting copyright ownership of the skinned mesh animations generated from MoCap data is a different area of research all together, since skinned mesh animations are generated by interpolation of keyframes. Authors in [21] have suggested a technique to watermark skinned mesh animations by randomly inserting watermark in mesh skin weights.

The work presented here is preliminary and focuses only on the space curve generated by one joint of the human skeleton used for MoCap animation. Further work is required to incorporate the motion constraints (temporal and spatial) while modifying the space curves of all joints of the skeleton. Future work also involves refining the algorithm such that it is resistant to various motion editing tasks [22] such as motion enhancement/attenuation, blending, stitching, shuffling, and noise removal.

Acknowledgment

The data used in this project was obtained from mocap.cs.cmu.edu. The database was created with funding from NSF EIA-0196217.

References

[1] J. Kim, D. Im, H. Lee, and H. Lee, "Watermarking curves using 2d mesh spectral transform," *IEEE International Symposium on Circuits and Systems*, pp. 2969 –2972, 2008.

[2] H. Yongjian, L. Heung-Kyu, and Z. Huafei, "Curve watermarking technique for fingerprinting digital maps," in *Proceedings of the International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, 2008, pp. 223–226.

[3] V. Solachidis and I. Pitas, "Watermarking polygonal lines using fourier descriptors," *IEEE Computer Graphics Applications*, vol. 24, no. 3, pp. 44–51, 2004.

[4] S. Thiemert, M. Steinebach, and P. Wolf, "A digital watermark for vector-based fonts," in *ACM Proceedings of the 8th workshop on Multimedia and security*, 2006, pp. 120–123.

[5] H. Gou and M. Wu, "Data hiding in curves with application to fingerprinting maps," *IEEE Transactions on Signal Processing*, vol. 53, no. 10, pp. 3988 – 4005, 2005.

[6] S. Li and M. Okuda, "Iterative frame decimation and watermarking for human motion animation," *ICGST International Journal on Graphics, Vision and Image Processing,Special Issue on Watermarking*, vol. 07, pp. 41–48, 2010.

[7] P. Agarwal and B. Prabhakaran, "Blind robust watermarking of 3d motion data," *ACM Transactions on Multimedia Computing and Communication Applications*, vol. 6, no. 1, pp. 1–32, 2010.

[8] P. Agarwal, K. Adi, and B. Prabhakaran, "Robust blind watermarking mechanism for motion data streams," in *Proceedings of the 8th workshop on Multimedia and security*. ACM, 2006, pp. 230–235.

[9] Y. Pu, J. Lin, M. Hung, B. Chen, and I. Jou, "Digital watermarking of mocap data based on singular value decomposition," *IEEE International Symposium on Knowledge Acquisition and Modeling Workshop*, pp. 932 –935, 2008.

[10] P. Agarwal and B. Prabhakaran, "Tamper proofing mechanisms for motion capture data," in *Proceedings of the 10th ACM workshop on Multimedia and security*, 2008, pp. 91–100.

[11] S. Li and M. Okuda, "Watermarking for progressive human motion animation," in *IEEE International Conference on Multimedia and Expo*, 2007, pp. 1259 – 1262.

[12] S. Yamazaki, "Watermarking motion data," in *Proceedings of Pacific Rim Workshop on Digital Steganography*, 2004, pp. 177–185.

[13] S. Yamazaki, M. Mochimaru, and T. Kanade, "Watermarking motion clips," in *Proceedings of the International Conference on Computer Animation and Social Agents*, 2005, pp. 171–176,.

[14] B. Studio, "Free motion capture data samples," http://www.beyondmotion.com.au/free_motion.html, 2009.

[15] R. Polikar, "Wavelets in signal processing," http://users.rowan.edu/p̃olikar/WAVELETS/WTtutorial.html, last Accessed August 5, 2010.

[16] S. Mallat, "A theory for multiresolution signal decomposition: the wavelet representation," *IEEE Transactions on Pattern Analysis and Machine Intelligence,*, vol. 11, no. 7, pp. 674 –693, 1989.

[17] A. Finkelstein and D. Salesin, "Multiresolution curves," in *SIGGRAPH: Proceedings of the 21st annual conference on Computer graphics and interactive techniques*, 1994, pp. 261–268.

[18] D. Philips, "Filter banks and discrete wavelet transform," http://www.engmath.dal.ca/courses/engm6610/notes/node6.html, 2003.

[19] N. Lawrence, "The university of manchester: Matlab motion capture toolbox," http://www.cs.man.ac.uk/ neill/mocap/.

[20] CMU, "Carnegie mellon university graphics lab motion capture database," http://mocap.cs.cmu.edu/.

[21] R. Motwani, A. Ambardekar, M. Motwani, and F. Harris, "Robust watermarking of 3d skinning mesh animations," 2008, pp. 1752 –1756.

[22] J. Lee and S. Y. Shin, "Multiresolution motion analysis and synthesis," Computer Science Department, Korea Advanced Institute of Science and Technology, Tech. Rep., 2000.