Towards Realistic Simulation of Skin Deformation by Estimating the Skin Artifacts

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Abstract

Simulating human skin deformation has wide application in the areas of computer graphics. Nowadays, human biomechanics are usually determined by the marker-based motion capture system. Nevertheless, it is known that the computation of human biomechanics is significantly affected by the displacement of the markers due to the skin artifacts. In order to obtain the prior skin parameters for the accurate deformation of the skin layer, we propose to quantify the skin movement artifacts in terms of the probability density using a set of skin markers. We demonstrate our works by measuring the skin artifacts of the lower limb of the human body. In order to estimate the skin artifacts, a set of skin markers was attached to the thigh. The least-square minimization was adopted to determine the rigid motion of the thigh segment. The determined motion of the thigh was then used to estimate the position of the markers at the bony landmarks. The displacement of the markers was computed by the distance between the measured and the estimated markers. We estimate the skin artifacts at the thigh during walking motion. It was found that the skin artifacts can be reasonably approximated with a Gaussian function.

Keywords: skin artifacts, motion capture system, probability density function, root means square displacement.

1 INTRODUCTION

Simulating human skin deformation has wide application in the areas of computer graphics. Nowadays, geometry based and physics based approaches are adopted to simulate the human skin deformation. Geometry based approaches such as free-form deformation (FFD) [1], [2] employs purely geometric techniques to model deformation. These approaches provide flexibility to for the users to control the deformation. However, it relies on the skill of the users for accurate simulation of the model. Recently, physics based approaches are becoming more popular. The most popular one is the mass-spring system [3], [4] because of its simplicity and capability to achieve real-time performance. Another approach to simulate human skin deformation is the finite element method (FEM) [5]. Despite numerous approaches have been proposed to simulate the skin deformation, the methods are still difficult to model skin deformation to be applied in biomedical applications because prior information are usually required for determining the deformation of the skin layers.

In this article, we propose to obtain the prior information of the human skin artifacts by using the skin markers. The magnitude of the skin artifacts is quantified in terms of the probability density measured by a cluster of skin markers. The proposed technique makes use of a set of skin markers to estimate the motions of the rigid segments. The least-square minimization is adopted to determine the motions of the rigid segments. The position of the markers was estimated based on the computed motions of each segment. Then, the displacement of the markers is computed by determining the distance between measured and estimated markers. We demonstrated our experiment results with walking motion.
2 Method

The proposed method determines the amount of displacement of the markers at the bony landmarks in two stages. The transformation between the first and the subsequent frames is firstly determined by the least-square minimization technique. The determined transformation is used to estimate the position of the markers at the bony landmarks. Then, the displacement of the markers is determined by the distance between the estimated and measured markers. A computer program developed using the Matlab (The MathWorks, Inc.) was adopted for computations.

A subject age 30 years old, 63 kg and 182 cm height was participated in this test. In our experiment, 7 markers were attached to the thigh. In which, 3 markers were attached to the bony landmarks including lateral epicondyle, medial epicondyle and greater trochanter. The rest of the markers were evenly distributed at the thigh segment. The 3D coordinates of each reflective marker was captured using the motion analysis system (Motion Analysis, Santa Rosa, USA). The system consisted of 8 cameras connected to a controlling computer. The capturing frequency was 120 Hz. The cameras were firstly calibrated before capturing the human dynamic motions. The trajectories of each reflective marker were the output of the system.

2.1 Estimating the Position of the Markers at the Bony Landmarks

Suppose a set of $N$ reflective markers ($N > 3$) is evenly attached to the skin of a rigid segment of the human body. The marker set includes the markers at the bony landmarks that we are going to estimate. The number of markers at the bony landmarks $N_b$ is less than the total number of reflective markers at the segment, such that $N > N_b$. The estimated rotation matrix $\mathbf{R}$ and translation vector $\mathbf{t}$ of the marker set between the $1^{st}$ and the $j^{th}$ frame is firstly determined by minimizing the typical least-square equation [6, 7].

Let $\{\mathbf{y}_{1}^j, ..., \mathbf{y}_{N_b}^j\}$ be the three-dimensional (3D) position of the markers at the bony landmark at the $j^{th}$ frame of the motion sequence. The estimated 3D position of the $k^{th}$ marker at the bony landmark at the $j^{th}$ frame, $\mathbf{y}_k^j$ is computed by

$$\mathbf{y}_k^j = \mathbf{R}\mathbf{y}_k^j + \mathbf{t}.$$  \hfill (1)

2.2 Computing the Skin Artifacts

Denote the position vector of the $k^{th}$ estimated and measured marker at the bony landmark as $\mathbf{y}_k^{1j} = \begin{bmatrix} x_k^j \\ y_k^j \\ z_k^j \end{bmatrix}$ and $\mathbf{y}_k^{2j} = \begin{bmatrix} x_k^j \\ y_k^j \\ z_k^j \end{bmatrix}$ respectively. The displacement of the $k^{th}$ marker in the $x$-, $y$- and $z$-directions at the $j^{th}$ frame between the estimated and the measured markers at the bony landmark is computed by

$$\mathbf{e}_k = \begin{bmatrix} e_{x_k}^j \\ e_{y_k}^j \\ e_{z_k}^j \end{bmatrix} = \begin{bmatrix} x_k^{1j} - x_k^{2j} \\ y_k^{1j} - y_k^{2j} \\ z_k^{1j} - z_k^{2j} \end{bmatrix}.$$  \hfill (2)
Then, the magnitude of the displacement of the $k^{th}$ marker due to the skin artifacts is determined by the norm of $e$

The root mean square displacement (RMSD) of the markers at the bony landmark are computed by

$$\text{RMSD} = \sqrt{\frac{\sum_{i=0}^{N_e} |e_i|^2}{N_b}}.$$ (3)

3 RESULTS

We demonstrated our method by estimating the displacement of the markers at the lower extremity in a walking cycle. Figure 1 illustrates the displacement of the markers at the bony landmark in the $x$-, $y$- and $z$-directions in terms of the probability density in a walking cycle. It was found that the maximum magnitudes of the markers displacement including greater trochanter, lateral epicondyle, medial epicondyle were 7.99 mm, 11.83 mm and 12.43 mm respectively. The RMSD of the markers were 5.12 mm, 7.11 mm and 6.05 mm respectively. The average maximum displacement in the thigh was 10.75 mm.

Table 1: The maximum displacement and the RMSD of the markers at the thigh (greater trochanter: GT, lateral epicondyle: LE, medial epicondyle: ME) and shank (lateral tibial plateau: LTP, medial tibial plateau: MTP, lateral maleoli: LM, medial maleoli: MM) during walking. All values are in millimetres (mm).

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<thead>
<tr>
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<th>Max. displacement (mm)</th>
<th>RMSD (mm)</th>
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<tbody>
<tr>
<td>Thigh GT</td>
<td>7.99</td>
<td>5.12</td>
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<tr>
<td>LE</td>
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<td>12.43</td>
<td>6.05</td>
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Figure 1: The probability density of the markers displacement during walking

4 DISCUSSION AND CONCLUSION

In order to obtain the prior information of the human skin artifacts for realistic skin deformation, a method that estimates the displacement of the markers due to the skin artifacts during walking has been presented. The method makes use of the skin markers instead of the bony markers as proposed in most of the literatures [8, 9] to estimate the skin artifacts. The setup of the experiment of the proposed method is simple and easy for implementation.
The propose method was validated by comparing with the results of a number of existing works [10, 11, 12]. Our results have indicated that the displacement of the markers due to the skin artifacts was approximately Gaussianly distributed. As illustrated in [12], the maximum magnitude of displacement was 10 mm and 6 mm respectively with up to 60 degrees of knee angle during a walking motion. The results agreed with our experimental results. In addition, the RMSD and the displacement of the markers at each bony landmark including the greater trochanter, lateral epicondyle, lateral malleolus etc. have been compared with the figures in [13] showing similar experiment results. In spite of our results the prior information of skin deformation have been compared with the results in the published articles, the results of the skin artifacts have not been applied in simulating the deformation of the skin artifacts. In the future, the measured skin artifacts should be applied to simulate the deformation of the skin layers towards an accuracy that can be applied in various biomedical applications.

REFERENCES