A FRAMEWORK FOR THE FUNCTIONAL IDENTIFICATION OF JOINT CENTERS USING MARKERLESS MOTION CAPTURE, VALIDATION FOR THE HIP JOINT.

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INTRODUCTION

The accurate identification of joint centers is in general a very important issue in biomechanics for the calculation of human body kinematics and kinetics. The hip joint center (HJC) for example is used in the kinematics to define the anatomical frame of the femur and in the kinetics for the calculation of hip moments generated by external loads. Many previous studies in literature pointed out the importance of an accurate identification of the HJC [Camomilla, 2006] demonstrating how it affects kinematics and kinetics of both hip and knee joint. Many algorithms have been developed in the past for the estimation of hip joint center using marker based kinematics (an exhaustive review can be found in [Camomilla, 2006]) under the hypothesis of spherical joint.

In this paper a framework for the accurate identification of the hip joint centers using markerless motion capture (MMC) method [Corazza, 2006, Mündermann, 2006] is presented. The theory behind is general and can be applied to every joint of the human body. In this work authors focus on the HJC since its representation as spherical joint is a generally accepted hypothesis. An experimental implementation of the method is reported together with validation results in virtual environment, showing errors in the on the order of one centimeter (i.e. the system spatial resolution).

METHODS

The idea underneath the presented functional joint center algorithm is based on the hypothesis that, for two rigid bodies connected with a ball and socket joint, there exists a *pivot* point *p* for which the motion can be described identically by either of the motions of the two rigid bodies.
The complete algorithm was applied to hip joint center identification, in both a virtual and experimental environment, through the following steps (Figure 1):
i) A 3D representation (visual hull) of the subject was reconstructed for every captured frame. The 3D representation has 1 cm spatial resolution (voxel size).
ii) Motion is tracked using a rough model and the method described in [Corazza2006]. Through a proximity-check the points of the visual hull belonging to the lower limb are identified (segmentation).
iii) The segmented lower limb is treated as a rigid body and the transformation matrices for the rigid body registration of couples of different frames were calculated, using Iterative Closest Point and Levenberg-Marquardt minimization based algorithm.
iv) The hip joint center is given by a least square solution of the (1) where R and t are the 3x3 rotation matrix and the 3x1 translation matrix derived from the 4x4 transformation matrixes of the rigid body registration.

$$\begin{bmatrix} R_1^A - I \\ \ldots \\ R_n^A - I \end{bmatrix} [JC] = \begin{bmatrix} -t_1^A \\ \ldots \\ -t_n^A \end{bmatrix} \qquad (1)$$

In equation (1) I is the identity matrix, n is the number of frames and index A refers to the segment of interest, which points coordinates are expressed in the system of reference of the proximal segment.
For the validation with synthetic data, a virtual character performed a functional start-arc motion through hip flexion-extension and ab-adduction as described in [Camomilla, 2006]. The 3D reconstruction was obtained by capturing from 8 VGA virtual cameras around the character, same setup used in the experimental trial.

RESULTS AND DISCUSSION

Results in the virtual environment are presented (Figure 2). After few iterations the error converges to sub-voxel or voxel level accuracies (voxel size=1 cm). The error with marker based technique for equivalent conditions is within 1 mm, on simulated data and not taking into account marker location estimation errors. Figure 2 also demonstrates the stability properties of the method with respect to large initialization errors.
Experimental trials were collected and the method implemented as shown in Figure 1.

SUMMARY/CONCLUSIONS

The presented work defines, in the context of MMC, a framework for the accurate functional identification of joint centers. The method applies well to the case of the HJC for which a validation is provided.

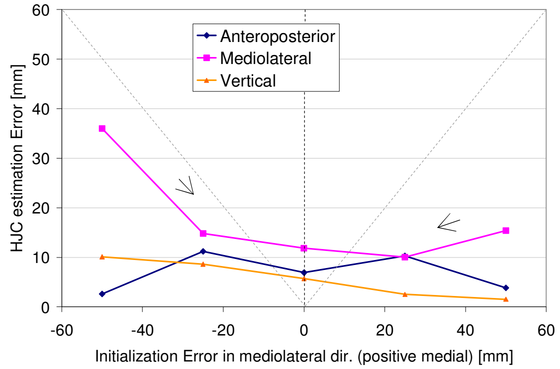

Figure 2: Algorithm stability diagram for large initialization error in joint center location in medio-lateral direction (worst case scenario).

Even though in simulated data marker based techniques [Camomilla, 2006] provide slightly more accurate results, the authors believe the presented method has greater potential in the experimental scenario where skin artifacts play a prevalent role, and with the advantage of no marker placement.

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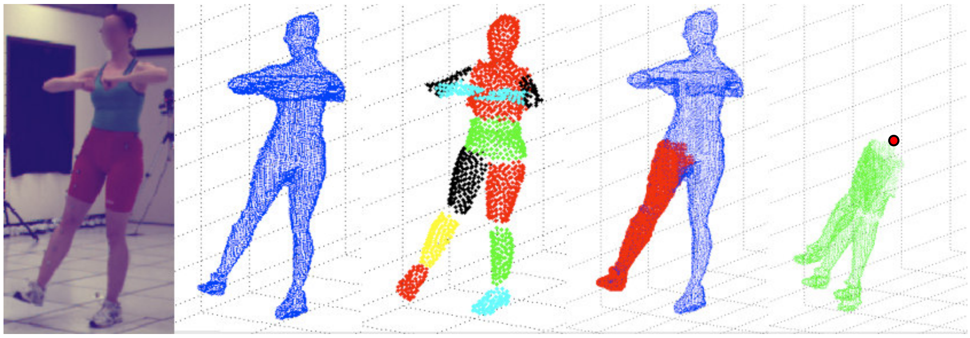

Figure 1: From the left: data acquisition, reconstruction of 3D representation, tracking result, segmentation, joint center estimation.