ESTIMATING THE MOTION OF THE HUMAN JOINTS USING OPTICAL MOTION CAPTURE SYSTEM

Junyoung Park, Fumihito Kyota, Suguru Saito and Masayuki Nakajima

Department of Computer Science
Tokyo Institute of Technology
Tokyo, Japan
E-mail: junyoung,kyota,suguru,nakajima@img.cs.titech.ac.jp

ABSTRACT

Motion capture systems allow to measure the precise position of markers on the human body in real time. These captured motion data, the marker position data, have to be fitted by a human skeleton model to represent the motion of the human. Typical human skeleton models approximate the joints using a ball joint model. However, because this model cannot represent the human skeleton precisely, errors between the motion data and the movements of the simplified human skeleton model happen. We propose in this paper a method for measuring a translation component of wrist, and elbow joints on upper limb using optical motion capture system. Then we study the errors between the ball joint model and acquired motion data. In addition, we discuss the problem to estimate motion of human joint using optical motion capture system.

Keywords: motion capture, human joint representation.

1. INTRODUCTION

Recently many methods have been proposed for estimating the human skeleton model using motion capture system [1, 2, 3]. In these methods a bone structure is represented as segments and joints connecting adjacent segments. In this model, called *ball joint model*, a joint has two parameters: the Center of Rotation (CoR) and the Axis of Rotation (AoR) to represent the joint state. However, when the joint rotates in the real human body, it is simultaneously slides due to several parameters such as shape of the two adjacent bones, the presence of ligaments that pass through the joint.[4] Therefore, the approximation of the bone structure with the traditional ball joint model is the source of errors that often occur between the generated motion data of the CG character and the real motion of the actor used to capture the motion data. Furthermore, modeling the real shape of the joints and measuring their accurate movements are challenging since not only there are many different types of joints in the human body, but joints also vary from one person to another.

We propose in this paper a method for estimating the motion of a joint when it rotates, and investigate the errors in the motion capture system. Then, we discuss the errors between the movement of the ball joint model and the movement of the real human joint from the captured motion data.

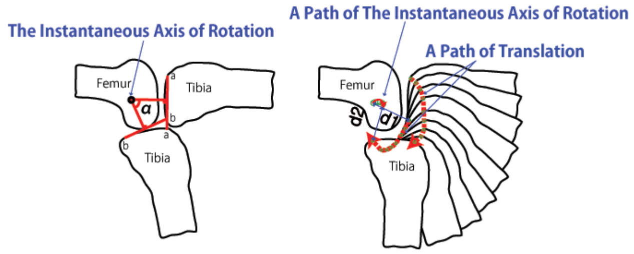
2. RELATED WORKS

Despite of many limitations, the ball joint model is widely accepted to represent the human skeleton joint model. Especially, there are many researches estimating the joint parameter using motion capture system. Using magnetic motion capture system, the method to estimate automatically joint parameter is proposed by O'Brin et al.[5] Using the least squares method, they calculate two vectors which indicate the link between each end point under the assumption that the vector from a sensor to joint is fixed in the local coordinate system of the sensor. However, because the human joint is different from the ball joint, the joint position which the two adjacent links' vectors indicate is not always same. Therefore a gap is happened between two adjacent links.

Using optical motion capture system, the method to estimate the joint parameters in gait analysis is proposed by Schwarts et al.[6] Attaching more markers than standard clinical marker set, they calculated more precisely the axis of rotation and the center of rotation of a hip joint. Since they assumed the ball joint model, this method cannot be adapted to other joints of the human body. The method to estimate a kinematic model of the in vivo CMC joint from surface marker measurements is proposed by Chang et al.[7] They consider that the CMC joint consists of three axis of rotation which makes two intersection points to represent the saddle joint. But they did not consider the curvature of the saddle joint which is related to the sliding component of the CMC joint.

To express the sliding motion of a human joint when it rotates, many methods to make a complex joint model have been proposed. Nierop et al.[8] proposed the maximal-coordinates approaches to make the ellipse joint and saddle joint in the hand. But this paper does not propose a constraint conditions between the redundant coordinates.

Spline Joints proposed by Lee et al.[9] can model general scleronomic constraints for multibody dynamics based on the minimal coordinates formulation. They represent the path and direction of a joint as a screw motion using C^2-continuous spline curves on SE(3). They provide also ge-



(A) Instantaneous Axis of Rotation when the joint rotate α degree.

(B) A Path of IAoR and A Path of Translation of a joint.

Fig. 1: The Instantaneous Axis of Rotation in the knee.

ometric data-fitting and smoothing algorithms for 1-DOF spline joint design. However they did not propose the data-fitting algorithms for two or more DOF spline joint because the general formulation of the spline surfaces on SE(3) is not known. Therefore, it is difficult to represent a 2-DOF joint from motion data. Moreover, the joint parameter which represents the status of the spline joint is hard to use directly in forward kinematics.

Using a optical motion capture system which is a measurement of high precision, we analyze the human joint as accurate as possible. In our approach, we consider the Translation Vector of the child link in a joint independently from the Orientation of the child joint. Therefore, we can concentrate the Path of Translation Vector of a joint from motion data.

3. METHOD

3.1 The Joint Parameters

The typical ball joint which is used to model joints of the human body, has two parameters; the Axis of Rotation (AoR) and Center of Rotation (CoR). However, in the human body, the value of two parameters are changed according to the rotation of joints. Fig.1(A) shows the method to calculate an Instantaneous Axis of Rotation(IAoR) using geometric properties. The intersection point of two perpendicular lines is an IAoR when the knee rotates α° flexion angle. If the flexion angle α close to 0, the IAoR can be calculated accurately. Fig.1(B) shows the path of the instantaneous axis of rotation in the knee joint. If we want to estimate accurate path of the IAoR, we have to know the accurate shape and position of the bones under the skins. It s very difficult task from motion data which are recorded the marker positions which attached on the human skins.

Because it is impossible to estimate the exact shape and the location of two adjacent bones from motion data, the estimation of the path of the IAoR is a very challenging task. Moreover, in the case of the translation component of the joint is complex, we cannot represent the rotation of the joint as a function of the axis of rotation, because the distances between the axis of rotation and the bone of the joint changes during rotation.($d1 \neq d2$ in Fig.1(B)) Therefore, we will consider the translation vector and the rotation matrix instead of the path of IAoR.

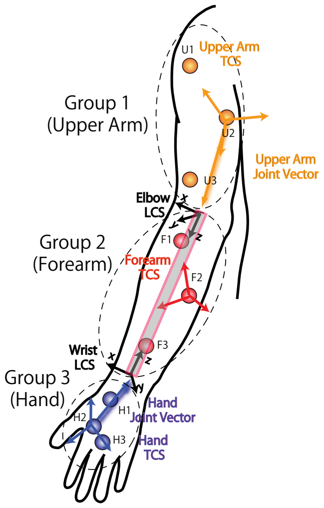


Fig. 2: The TCSs and FCSs that define the upper arm and the forearm and hand dorsum segments adjacent to the elbow joint and wrist joint on the Upper limb.

3.2 Experimental Setting

In order to approximate the path of translation using optical motion capture system, we attached nine markers divided into 3 groups on the upper limbs (Fig.2). The marker positions are decided from three points of view; 1) the effect of the skin deformation is reduced, 2) a bone movement can be measured easily, 3) distances between markers on a group become maximum to reducethe effect of noise(Fig.3).

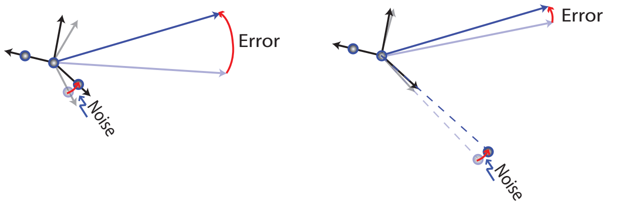


Fig. 3: Even the noise level is same, the rotation of the coordinate system influenced by noise is different from the distance between the markers.

We captured the target motion using the passive optical motion capture system of Motion Analysis which consists of 5 cameras, and calibrated before the experiment. We chose wrist joint and elbow joint as target joints. For wrist joint, full ranged angle is captured, for elbow joint, the angle of flexion and extension positions are only captured, but pronation and supination posture is fixed. because it is not related to the path of translation vector in the joint. The acquired motion data is preprocessed to recover the marker tracking failure and to classify the markers into 3 groups using the marker distribution and labeling method for optical motion capture system (Kurihara et al.[10]).

Using the markers on each group, we can define technical coordinate system (TCS) which related to the marker position. Fig.2 is a marker position settnig for the right upper limb to measure the path of translation in the elbow joint and the wrist joint. Markers 1, 2, and 3 define the TCS of the upper arm segment, $F1, F2$, and $F3$ define the TCS of the forearm segment, and $H1, H2$, and $H3$ define the TCS of the hand dorsum segment.

We can describe a movement of the TCS using a transform $\mathbf{T}(f) = [\mathbf{R}_T(f), \vec{p}_T(f)]$ which consists of a rotation matrix $\mathbf{R}$ and a translation vector $\vec{p}$ at a frame f. Then the motion of three markers in a group can be translated to the motion of the TCSs.

3.3 Approach

From the motion of the TCSs, we can define two joint center vectors, $\vec{v}$ and $\vec{v}_c$, on the TCSs of the adjacent links respectively. The joint center vector indicates the joint position from the origin of its TCS.

To describe a movement of a joint using the two joint center vectors, we define a local coordinate system(LCS) of a joint in the TCS of a link. We call this link as a parent link, but it dose not mean the links has a hierarchy in the two link. A origin of the LCS is represented $\vec{v}$ in the TCS of its parent link, and the z-axis of the LCS has the same direction to the parent link, the other axes of the LCS is defined by the direction of the axis of rotation of the joint (Fig.2).

Assuming that the target is a ball joint, we can derive two joint center vectors v and v_c, on the TCSs of a parent link and a child link respectively by the method of [1, 2, 3]. However actual joints in human body are not ball joint so that this assumption makes error. The point indicated by v_c which is a fixed point on the TCS of the child link moves on the TCS of the parent link in real cases.

We investigate how widely v_c moves. The moving area depends on selecting the potision of v_c. When v_c is set close to an average rotation center, the trajectory area becomes small. We adapt the point, whose moving area is minimum, as v_c.

The spread points in Fig.4 shows v_c trajectories. These are calculated from a same captured motion data but v_c positions are different.

From the definition, the maximum distance between two joint center vectors,$\vec{v}$ and $\vec{v}_c$, is the maximum translation vector of the joint.

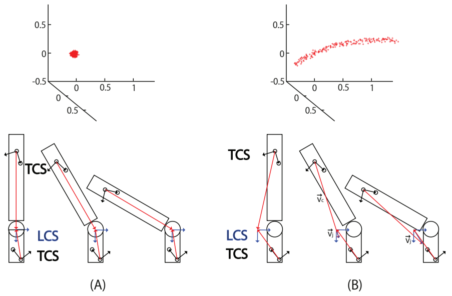


Fig. 4: If the estimated joint center vector does not indicate the center of rotation, the volume of the vector $\vec{v}_j$ makes a shape on its LCS.

3.4 Noise Analysis

Because we use a motion capture system as a measuring equipment, the motion data includes some noise from the system. Therefore, in order to measure the noise from the motion capture system, we measured postures of a lamp stand which is made by the rigid link and hinge joint. We used only 2 cameras which the worst case for measuring the position of a marker in optical motion capture system.

Fig.5 shows the path of translation vector for a joint of the lamp stand. Because we measured the motion of a hinge joint, we can assume the ideal path of translation vector is just one point on the origin, and the others are made by the noise from the motion capture system. Due to the result, the noise makes a surface which has a direction. This surface is a part of a sphere surface, whose center is the origin of the TCS of the child link, and a radius of the sphere is the length of the joint center vector $\vec{v}_c$. It comes from the model structure which we mentioned before (Fig.3). If the length of the joint center vector of each TCS is longer than the distance between the markers, the path of translation vector is affected more then the noise emphasis at some direction on the x-y plane. However, the noise range of z-axis affected the noise of marker almost directly. So we can estimate the maximum range of noise from our motion capture system is about 3mm on the z-axis direction, and the noise of the other direction is depend on the ratio of the length of the vector to the distance between the markers.

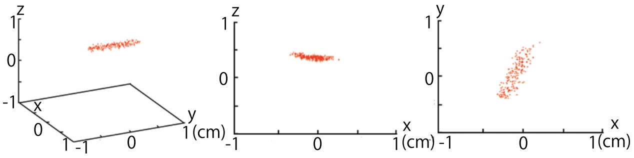


Fig. 5: The path of translation vector on LCS of a hinge joint

3.5 Result

Using our method, we extracted a path of translation vector of the wrist joint and the elbow joint from upper limb motion data. Fig.6 and Fig.7 are the results on the wrist joint and elbow joint respectively. The points indicated by the translation vector of the joint on its LCS, shows the breadth of sliding when the joint rotates.

From the results, the wrist joint translates about 1.5cm when the wrist joint rotates with a flexion-extension direction, and adduction-abduction direction. And the elbow joint translates about 1cm when the elbow joint rotates in a flexion-extension direction.

However, because some parts of the results comes form the noise in the motion capture system, the range of translation of the wrist joint is about 1cm, and the elbow joint slides about 0.5cm when we consider the spectrum of noise in the wrist joint and elbow joint. Because the result of the elbow joint makes a curved surface when it rotates, the joint

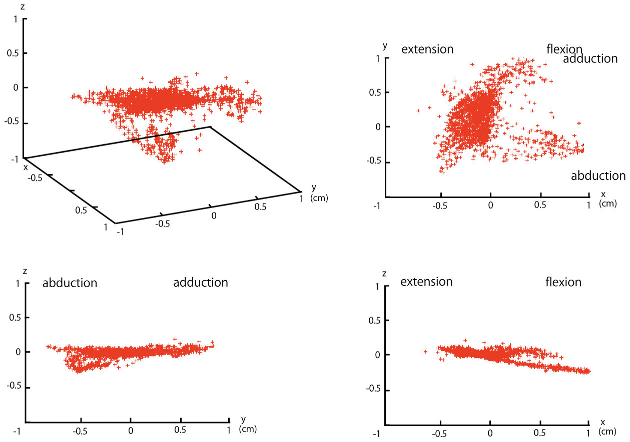


Fig. 6: The path of translation vector on wrist joint

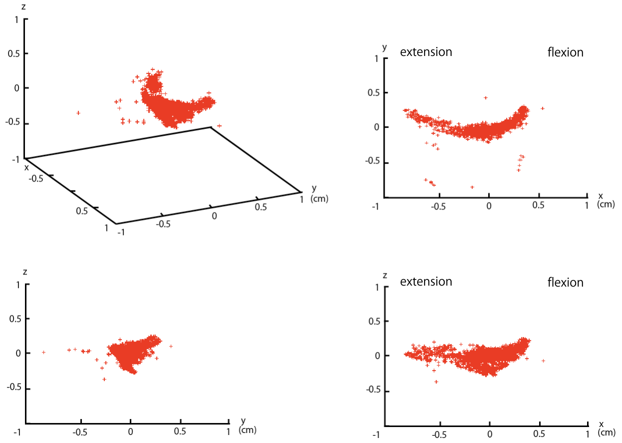


Fig. 7: The path of translation vector on elbow joint

center vector of the elbow joint may be not perfectly optimized. We estimate the reason comes from the noise of the motion capture system, and the deformation of skin. Nevertheless, we can assume the maximal translation vector in the elbow joint is less than 0.5cm in the worst case, and the shape of elbow joint is more spherical than the shape of wrist joint. And this is a corresponding result to a anatomic fact.

4. CONCLUSION AND FUTURE WORK

We proposed, in this paper, the method to extract the path of translation vector of a human joint from the motion data. From the result, we found the range of translation of human joint. From that, we can say the human joint cannot be representable by a ball joint because the joint translates simultaneously, when it rotates. In this paper, we did not consider the deformation of the skin because, unlike the noise from motion capture system, the amount of deformation of the human skin is hard to measure using motion capture system. Presumably this noise is related by the amount of the joint rotation.

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