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# Simultaneous global inverse kinematics and geometric parameter identification of human skeletal model from motion capture data

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ABSTRACT

This paper presents a method to identify the geometric parameters of a human skeletal model from motion capture data. For the identification, the joint trajectories have to be computed from the data at the same time. The method solves both the inverse kinematics and the geometric parameter identification simultaneously. In the method, the parameters are modeled as the generalized coordinates of virtual mechanical joints. It solves the large-scale inverse kinematics to compute the generalized coordinates at all given time-series instances and the time-invariant virtual coordinates. Though the method is based on the nonlinear programing, the computation is accelerated by decomposed gradient computation based on recursive Newton–Euler formulation. The method was tested on a 34-DOF human skeletal model using a motion capture system, and the results of the geometric parameters and the time-series coordinates are to be shown. The method was also applied to obtain a subject-specific musculoskeletal model.



## 1. Introduction

The development of robotics computation theory [1–3] has been providing a new clue to the mythology of human motion analysis. Especially, the kinematics and dynamics computation techniques of a humanoid robot can be applied for it [4], because of the similarity of appearance. They enable the recent applications such as computer animation [5], musculoskeletal modeling [4,6], mass property identification [7], and so on. Those applications commonly require the process of motion capture at the beginning of the analysis.

Most popular methods of motion capture measure the position of the optical markers located on an object. For applications of human motion analysis, the joint trajectories are computed from the measured trajectories of the markers. Since the markers usually cannot be attached to the center of the joints, the geometric parameters of a human skeletal system and the offsets of each marker from the center of the nearest joint are also needed to be known in the computation process. A human skeletal system is often modeled as a multi-rigid-body system whose links are connected by mechanical joints, such as revolutionary or spherical joints [4,6]. Under the geometric constraints about the connectivity of rigid bodies, the joint trajectories and the geometric parameters can be solved simultaneously by nonlinear programming techniques [8,9]. As the nonlinear programming requires large computation cost, those methods usually divide the skeletal model into two-link sub-systems. Since the divided sub-system lacks the whole connectivity information, it tightens the condition of marker placement to structurally identify whole parameters; for example, the number of markers in the two-link system must be at least four, and each link has at least

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one marker [10]. The placement condition becomes a problem when analyzing the skeletal model that has many degrees of freedom.

For the estimation of joint trajectories, the robotics inverse kinematics techniques have also been applied [4]. In the kinematics computation of a robot, the joint angles (or the generalized coordinates) are used to represent the joint trajectories. Since the geometric constraints about the connectivity are eliminated in advance, the joint trajectories can be solved by the nonlinear programing without constraints. In addition, the number of variables used in the optimization is also reduced. Therefore, the computational complexity can be reduced compared to the method shown in the first paragraph. However, the problem of the robotics approach is that the geometric parameters are needed to be known in advance, because the parameters of a robot are usually determined when manufacturing it. Though the parameters of a human are often measured before capturing, it takes a skill and effort to measure accurately all the distances between joint centers.

This paper proposes a method to simultaneously solve the inverse kinematics and geometric parameter identification. Though the method is based on the nonlinear programing, the computation is accelerated by robotics inverse kinematics approach. The joint trajectories are represented by the generalized coordinates of each time instance, and the geometric parameters are modeled as the generalized coordinates of virtual mechanical joints which are constant values during all time sequences. The method solves the large-scale inverse kinematics to compute all the generalized coordinates of all instances and the time-invariant virtual coordinates. It is solved by the recent large-scale inverse kinematics technique [11].

The similar formula is found in the methodology used in the calibration of serial robot chains, where both the kinematics parameters and joint offsets are calibrated at the same time by minimizing a least squares error criterion [12]. Those techniques are recently used for the calibration of the humanoid robots [13]. The critical difference between the calibration of humanoid robots and humans is whether or not the joint angles can be measured directly, for example, by encoders. Though the gains and the offsets of encoders are unknown, the relative and scaled joint angles are available in the calibration of robots; all the unknown parameters in the calibration can be regarded as time invariant ones. On the other hand, in the identification of the parameters of the human skeletal system, the joint angles of each time instance are also unknown. Therefore, the joint angle trajectories and the geometric parameters generally have to be identified simultaneously, which requires huge computation cost. The proposed method can overcome this computational problem.

## 2. Robotics inverse kinematics approach

This section shows a robotics inverse kinematics approach to compute the joint trajectories of a skeletal model from the given marker positions (Fig. 1).

Let $N_J$ be the number of DOF of a multi-body system, $N_L$ be the number of links, $N_M$ be the number of markers, and $\boldsymbol{q} \in \mathbb{R}^{N_J}$ be the vector of the generalized coordinates. Each marker is attached on only one link as shown in Fig. 1. $\boldsymbol{p}_i(\boldsymbol{q}) \in \mathbb{R}^3$

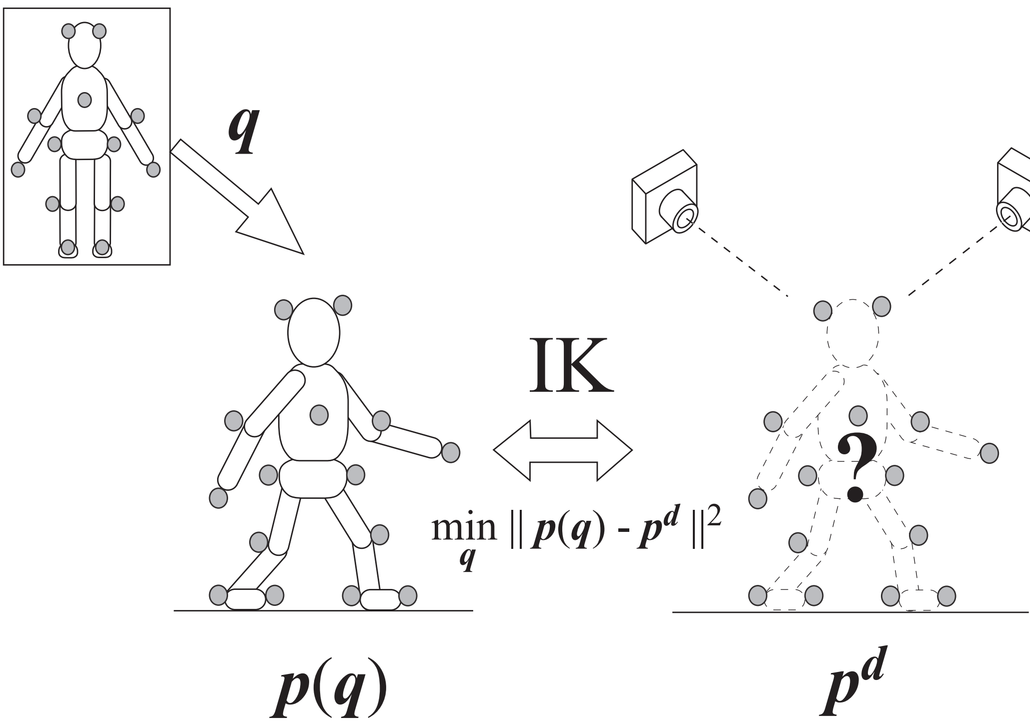


**Fig. 1.** Inverse kinematics (IK) problem of human skeletal model from motion capture data.