Biomedical Signal Processing and Control 39 (2018) 130–138

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Verification of the blobby quaternion model of human joint limits

Agnieszka Szczęsna

Institute of Informatics, Silesian University of Technology, ul. Akademicka 16, 44-100 Gliwice, Poland

ARTICLE INFO

Article history:
Received 14 December 2016
Received in revised form 17 May 2017
Accepted 20 July 2017

Keywords:
Quaternion
Isosurface
Quaternion volume
Joint limit
Motion capture

ABSTRACT

The quaternion blobby model for constraining the joint range of motions based on real captured data has been proposed. The boundary of the feasible region is modeled using a geometric approach. The proposed method aims at generating an implicit representation of quaternion volume field boundaries which represent the space of all possible and permitted orientations in the joint. The implicit surface is generated as an isosurface of quaternion volume. This approximation volume is determined based on data captured by the optical motion capture system and transformed to unit quaternions. The isosurface is generated from the blobby model which is popular as a solid object modeling tool in computer graphics. The obtained quaternion orientation space represents valid orientations and allows to reproject any orientation to the nearest valid ones. The model was verified based on motion captured shoulder joint data.

1. Introduction

With the popularization of motion acquisition methods, motion analysis is a active area of research. Proposed advanced solutions for motion capture, analysis and synthesis have a wide range of different applications [1–7].

This work concerns a joint limit model built on the basis of reference data acquired through the mocap system without need more complicated medical procedures like CT, MRI [8,9]. The model can be the base for subsequent tools like tracking, classification or comparison of joint limit ranges. It can be essential in automated methods, such as physical simulation, forward and inverse kinematics. Joint limits are used, for example, in defining the pose of a character for animation. Application of joint limits can overcome errors in pose estimation during motion tracking. For example, in inertial motion capture systems estimated orientations are based on signals from IMU (inertial measurement unit) sensors. The errors can be large (about 10 degrees), so introduction of joint angles constraints can improve the pose calculation [10,11].

Joint motion articulating surface is an important concept for the assessment of joint wear, stability and degeneration as well as to determine the proper diagnosis and treatment of joint diseases [12]. The method described in this paper uses the concepts of joint motion articulating surface.

Current tools, especially animation editors, express joint limits in the range of three Euler rotation angles (box model) without taking into account dependencies between the angles. In opposition, this paper presents a quaternion based model to represent the range of valid joint orientations. This representation allows characterizing intra- and inter-joint dependencies.

The purpose of this study is to present the general and flexible blobby quaternion model of joint orientations. The model can represent the individual person's joint, or be a general model built on a broad set of data. The blobby model is parameterised be two parameters and can be based on different metrics. In paper two metrics are used: Euclidean and geodesic quaternion distance function. The model is based on captured motion data. Motion acquisitions methods, like optical or inertial motion capture systems, are becoming more and more popular so such model can be easily obtained.

The paper also describes the model verification performed based on the motion captured shoulder joint data. The analyzed joint is a three degree of freedom (3-DOF) ball-and-socket joint which normally allows a wide range of movements.

The most models are verified by visual verification of simulation or tracking results with using the model. Quantitative assessments are not included. In the following the quantitative results as a number of incorrect orientation in test set are presented. The results shown, that quaternion blobby model can be better fitted to real joint limits that more general models.

2. Human joints

A system of rigid bodies interconnected by joints is called a kinematic chain. Joints are movable connections between skeleton elements (rigid bodies) and allow relative motion between them with imposed constrains.

http://dx.doi.org/10.1016/j.bspc.2017.07.029

Table 1
Joint limits models summary.

Method	Model data	Swing and twist	Limit source data	Orientation verification	Orientation projection
Box model	Minimum and maximum values of row, pitch and yaw angles (RPY)	No correlated	Biomechanics data, interactive tool	Checking if the angle is within a defined range	Yes
Spherical polygons	Spherical polygon on the unit sphere with centre in the middle of a joint rotation	Modelled independently	Biomechanics data, interactive tool	Testing whether a longitudinal axis intersects the sphere inside a spherical polygon	No
Sinus cone	Irregular cone with the apex at the functional centre of the joint	Modelled independently	Biomechanics data, interactive tool	Limiting the longitudinal axis of joint motion to the interior of cone	Yes
Reach cone	Spherical polygon on the surface of reach sphere	Modelled independently	Biomechanics data, interactive tool	Detecting if longitudinal segment axis intersects the unit sphere inside or outside the reach cone polygon	Yes
Triangular Bezier spline surface	Workspace of a joint as a parametric surface (triangular Bezier spline) which interpolate tip bone positions points	Modelled independently	Mocap data (distance of two markers)	Intersection with triangular Bezier patch	No description
Distance cone	The geometry boundary of the joint orientations (in Euler angles) feasible region	Modelled correlation	Mocap data	Testing value of implicit function	Yes
Implicit surface (RBF)	Implicit function on set of base points which are exponential map of unit quaternions	Modelled correlation	Mocap data	Testing the value of implicit function	Yes
QuTEM	Ellipsoidal boundary (isodensity contour) of density model based on points which are an exponential map of orientation quaternions	Modelled correlation	Mocap data	Detect inclusion with ellipsoid boundary	Yes

In humans, motion is dictated by the shape of the bones in the joint and by supporting soft tissue, e.g. muscle attachments and joint capsules (ligaments). To model human movement it is necessary to consider *synovial joints* which contain a fluid-filled cavity between two or more bones. The structure of the joint determines the functional potential for the joint [13,12].

To verify the joint limits model the shoulder joint has been chosen. The shoulder complex has three articulations, the sternoclavicular (SC) saddle joint, the claviscapular (CS) plane joint and the glenohumeral (GH) ball and socket joint. We are particularly interested in the GH joint (referred to as the shoulder joint). This is a synovial ball and socket joint and involves articulation between the glenoid fossa of the scapula (shoulder blade) and the head of the humerus (upper arm bone). Due to the very limited interface of the humerus and scapula, it is the most mobile joint of the human body. A shoulder joint complex is often treated as one joint to reduce the size of the transformation hierarchy. Therefore a constraint model with a greater range of motion is required.

Normal movements of the shoulder joint (GH), are: flexion and extension, abduction and adduction, horizontal abduction and adduction, internal and external rotation [13,12]. The example of biomechanics models of the arm were created with joint limits based on sinus joints [14,15], the box model [16] and with the definition of the arm-reachable workspace (ARW) [17].

3. Representation of joints limits

In this subsection some reviews of methods to model joint limits are presented. Summary information is collected in Table 1.

Most current tools which use joint limits allow definition of limits on individual rotation angles that do not account for dependencies between those angles. Each DOF of a joint is treated individually and limits are described by minimal and maximal values of three Euler angles. This is the box limit model which is the prevalent model for joint limits, used in file formats such as Acclaims ASF/AMC and in animations tools such as Maya or Blender. Box limits are computationally cheap and easy to use. Modeling by use of Euler angles can give a gimbal lock effect which refers to the loss of one rotational degree of freedom. Independent range specification is inadequate for joints with more than one DOF.

Other methods, the spherical polygons [18,19], sinus cone [20,21,14] or reach cone [22] conceptually, are very similar and define the set of directions that can actually be taken by the longitudinal axis of joint. In that configuration the swing and twist must be considered separately, because the twist is rotation around the longitudinal segment axis. Such restrictions do not have more general models built on captured data.

In [23] the workspace of a joint is modeled as a triangular Bezier spline surface. The described method is used to construct a model using motion captured data for the position and orientation of the upper arm through measurement of marker distance placed at the elbow from the humerus. The surface model defines only the angular motion (swing), the restriction of twist is modeled as a separate elevation function. The intersection test is computed using the fact that the triangular Bezier patch can be efficiently subdivided, and using octree data structure that cuts the search space.

The distance cone is a local joint constraint model for a joint which is based on embedding motion captured data points in a signed distance field. A region of feasible orientations is defined by implicit function on Euler angles [24,25].

Another method for determining joint limits based on real data is a method using implicit surface as a boundary of quaternion joint orientation space [26,27]. Radial basis-functions (RBF) are used to reconstruct an implicit surface representation of the boundary of the feasible quaternions. The method presented in this paper also computes an implicit model based on real data. In opposition to cited work, it uses different mathematical volume approximation of quaternion joint orientation space. The blobby model better sup-