Modeling Ranges of Limb Motion for Real-Time Inverse Kinematics

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1 Introduction

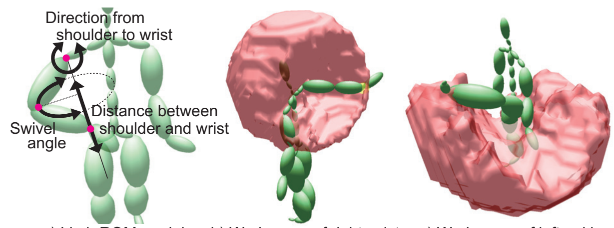
Accurate modeling of range of joint motions (joint ROM) is a fundamental problem of articulated figure animation. The joint ROM should be carefully designed to avoid an impossible pose, requiring tedious work because of the complexity and extensiveness of human joints, especially shoulders and hips. Although many joint ROM models have been proposed in the field of biomechanics and graphics, they still have two issues. The first is that a ROM of spherical joint is defined in a spherical domain. A traditional approach respectively defines a range of yaw, pitch and roll of joint rotation, which often causes an unexpected artifact due to the nonlinearity of the Euler angles. Another method uses a sophisticated parameterization of 3D rotation [Herda et al. 2005] or a 3D geometrical model to represent a boundary of joint orientation. These methods, however, require extra computational cost. The second issue is that a joint ROM is separately defined for each joint. Previous models often neglect a strong dependency between adjacent joints; a shoulder's joint ROM varies depending on elbow angle for example. A complex mechanism is therefore required to simulate such dependency [Herda et al. 2005].

We propose a model to represent *ranges of limb motion (limb ROM)*. The key idea of limb ROM is to define a space of possible pose of a limb [1], instead of defining ROM of each joint. A limb ROM is composed of a valid 3D workspace of the wrist and a range of swivel angle at arbitrary location in the workspace; "swivel angle" [Tolani et al. 2000] denotes a rotation angle of the elbow around an axis with which shoulder and wrist are connected. Our method has three contributions: 1) our method successfully simulates a dependency between ROM of a joint and rotation of its neighbor because a limb ROM model limits movements of multiple joints simultaneously. 2) A compact limb ROM model is automatically estimated from a sparse collection of example poses based on an empirical assumption. 3) Our limb ROM model is well suited to a real-time inverse kinematics (IK) technique [Tolani et al. 2000] because our model consists of wrist position and swivel angle, both of which are the control inputs of the IK solver. Prior to executing the IK solver, an impossible limb pose is efficiently avoided by relocating the wrist position into the valid workspace and adjusting swivel angle while fixing the wrist position.

2 Technical approach

2.1 Model construction

A limb ROM model represents a valid range of directions from shoulder to wrist, and range of swivel angle and distance from shoulder to wrist along a direction as shown in Figure (a). This model is constructed from a collection of example poses using a non-parametric regression technique. An example data of the non-parametric model is composed of wrist position and swivel angle in a shoulder's local coordinate system. As a collection of examples is very sparse in practice, missing data is interpolated from the measurements. To improve the interpolation accuracy, the dimensionality of the interpolation problem is reduced on an empirical assumption: a range of swivel angle changes depending on only direction from shoulder to wrist without being constrained by a distance to wrist. Based on this assumption, example data is mapped onto a surface of unit sphere on which a direction from shoulder to wrist is represented by a point. The point on the surface stores a distance to wrist and a swivel angle of the example. Missing data is then interpolated using uniform sampling by following four steps: Sampling points are first distributed uniformly on the spherical surface. Secondly, minimum and maximum values of swivel angle and those of distance to wrist are respectively searched within a certain radius around each sampling point. Thirdly, the searched values are stored in each sampling point, and points having no value are removed. Finally, a valid region on the spherical surface is defined by detecting a closed outer hull which includes all available sampling points.



a) Limb ROM model b) Workspace of right wrist c) Workspace of left ankle
(These bumpy surfaces are caused by simple marching cubes)

2.2 Validation of limb poses

A limb pose is validated using our model in two steps: A direction to wrist is first validated by checking whether it is mapped within the valid region on the spherical surface. A distance to wrist and a swivel angle are then checked whether they are within the range that is calculated using a k-nearest neighbor interpolation of the samples.

Our method provides a straightforward solution to synthesize a possible pose using an IK solver designed for human limbs [Tolani et al. 2000]. Our model enables a constant-time validation and correction of wrist position and swivel angle prior to an execution of the IK solver, whereas the previous method incorporates a joint ROM with an optimization framework.

3 Discussion

We created limb ROM models of arms and legs using motion capture data of a loose-limbed actress. Figure (b) and (c) show an approximated workspace of right wrist and left ankle, respectively. These results demonstrate reasonable accuracy of our model. One major limitation is that our model still requires a large amount of memory which increases according to the number of sampling points. Our future work includes an investigation of a more compact, parametric limb ROM model, which would be accomplished by using a polynomial approximation technique.

References

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Tolani, D., Goswami, A., and Badler, N. I. 2000. Real-time inverse kinematics techniques for anthropomorphic limbs. *Graphical Models 62*, 5, 353–388.

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[1] In this paper we explain about only upper limbs.