VISUALIZING ORIENTATION USING QUATERNIONS

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KEY WORDS: animations, motion analysis system, kinematics

INTRODUCTION: Visualization of 3D kinematic data presents special challenges, not only in terms of hardware requirements, but also in terms of the mathematics used to describe it. The ISB Standardization and Technology Committee has been working to standardize methods for representing kinematic data, particularly in the definition of coordinate systems and the representation of spatial orientations. In this presentation we will show that, although the ISB's recommendation to regard a segment's orientation as an ordered series of rotations may be useful for reporting and comparing results, it is not particularly suitable for 3D animation. The fundamental problems in ordered series of rotations will be briefly summarized. We will contrast this with the algebraic elegance of the quaternion and its usefulness as a rotation operator. The advantages of quaternions will be visually demonstrated by showing them "in action" in examples of real-time key frame animations.

In biomechanics, the spatial orientation of a rigid body is usually described using 6 degrees of freedom, which describe a translation and an ordered series of rotations (Euler or Cardan angles). At first glance, these series of rotations seem to be intuitive as they represent rotations about its principal axes. However, ordered series of rotations have some inherent fundamental problems like gimbal lock, or loss of a degree of freedom. Another problem is that there are 12 different combinations of rotations to achieve a particular spatial orientation. This is not only confusing but it also introduces problems when calculating inverse or forward dynamics. For example, a naive approach is to assume that an angular velocity represents the rate of change of Euler angles, so we can obtain them by integrating the angular velocity vector somehow. But which one of the 12 sequences is the right one? It is possible to calculate the rates of change of the Euler angles for a given rotation sequence, but this is mathematically tedious at best.

An important issue in animation is that of interpolation between key frame orientations, a technique that will allow animation at the highest possible frame rate. Interpolating Euler angles between different orientations will result in jerky or unnatural movement, especially in orientations at or approaching gimbal lock. Interpolation is also difficult to achieve when rotation matrices are used for representing orientations. Since rotation matrices can represent transformations other than rotations (like shear), special conditions must be enforced to ensure that these matrices only represent orientation (like orthogonality conditions, and a determinant of +1).

Quaternions do not suffer from the above problems. Quaternions are the preferred rotation operators in fields as diverse as chemistry, robotics, space shuttle control, 3D games, and virtual reality. At first glance they may seem mathematically strange objects, because they are a sum of a scalar and a vector. But quaternions have properties that make them excellent rotation operators. Let q denote a quaternion. The operation $q\mathbf{v}q^{-1}$ rotates a vector $\mathbf{v}$ about the axis of q through twice the angle of q. This is true for any vector $\mathbf{v}$ and any nonzero quaternion q. Quaternion multiplication can be used to compound rotations. If quaternions q_1 and q_2 represent rotations R_1 and R_2 respectively, then the quaternion product q_1q_2 represents the composition R_1R_2. Quaternion powers can be used to iterate or "divide" rotations. This allows for smooth interpolations between orientations. We will present examples of animation of motion capture data, where a segment's orientation is smoothly interpolated between key-frames to achieve the highest frame-rate possible on any given hardware. This method works well even if the key-frame data driving the animation has been sampled at a relatively low rate; it makes quaternions especially useful for real-time 3d animation of fast sports movements using off-the-shelf hardware.

CONSCLUSION: We conclude that Euler angles are not suitable for representing orientation in animations. Not only do they introduce computational overhead into simple calculations, but they have more fundamental problems associated with them. Quaternions do not have any of these problems; they are the preferred rotation operator in many fields. Quaternions are particularly useful in real-time or key-frame animations. Quaternion multiplication or “division” is computationally inexpensive and allows for fast and smooth interpolation of orientations. In this presentation we will visually demonstrate that using quaternions smooth key-frame animations of kinematic data can be achieved on relatively modest hardware.

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