Preface

Anatomical Movements

This book presents a mathematical approach to the description of anatomical movements. The methods described can be applied to any rotational movement, but they work particularly well with anatomical movements because anatomical movements are purposeful, generally multi-jointed, rotations in three-dimensional space, which are controlled by the nervous system to achieve a particular goal. Their purpose usually requires that they not only bring a part of the body into a particular location in space, but that it is properly oriented. Orientation is a very important component of anatomical movements.

Anatomical movements are generally rotations that occur in joints, where one bone moves upon another about an axis of rotation. Many anatomical movements are concatenations of several rotations, occurring in multiple joints, where the orientation of each joint is contingent upon movements in other joints. This type of organization leads to a complex interplay between several rotations.

Because movements generally occur in three dimensions, they are nonlinear in the sense that the order of rotation is critical to the outcome. Flexion followed by lateral rotation leads to a different outcome than lateral rotation followed by flexion. In mathematical terms rotations are non-commutative.

A consequence of all of these features of anatomical rotations is that they rapidly become very complex to describe and consequently difficult to plan or control and yet the central nervous system does so with remarkable elegance. What we discover about the nature of anatomical movements must ultimately tell us something about the nature of neural control.

Description of Anatomical Movements

The description of anatomical movement is often difficult. The most common method, in terms of cardinal planes, works reasonably well as long as one is starting from the anatomical position and moving in a cardinal plane. Otherwise it becomes both cumbersome and ambiguous. The nomenclature of that approach has essentially no predictive power and it ignores orientation or conflates it with position or location. The nomenclature also assumes many, generally unstated, rules. For instance, which direction is left side-flexion of a vertebra? Is it the superior or inferior surface that is moving left? Is it the observer's left or the skeleton's left? Would it still be left sideflexion if the axis of rotation passes through the superior margin of the vertebral body? What if the axis of rotation is tilted relative to the cardinal axes of the vertebra? There are conventions for all these points, but they are usually unstated.

The system of description introduced here is precise and concise, intuitive, and adaptable to the level of one's knowledge about the movement. The logic of rotations in three-dimensional space is embedded in the notation and it allows one to pass directly from the anatomical description to computation of the consequences of the anatomy for its movements. There are no cardinal planes in the usual sense of the term, but the concept is embedded in the description of a structure's anatomy and its movements in terms of a universal coordinate system that is automatically defined as part of the anatomical description. The approach deals as easily with oblique and curvilinear movements as with movement in a cardinal plane.

The approach developed here grows out of the concepts developed by MacConaill (MacConaill 1964; MacConaill 1966) and popularized by MacConaill and Basmajian (MacConaill and Basmajian 1977). It also draws upon the approach of Kapandji (Kapandji 1974). A modern summary of these concepts may be found in Gray's Anatomy (Standring 2005). However, none of these approaches is computational in the sense that they provide a formal linguistic structure in which to write an anatomical description so that it may used to compute the consequences of the anatomy for movement.

Quaternions

The approach introduced here is computational. One is able to construct a description of the anatomy of a joint or other anatomical structure and compute the consequences of the anatomy for movements of the structure. This is possible because of two concepts that form the basis of the anatomical description: quaternions and framed vectors.

Quaternions are a form of hypercomplex number, with four components, that were discovered by Sir William Rowan Hamilton in 1843 (Hamilton and Joly 1869). They are a generalization of complex numbers that is ideally suited for the description of rotations in three-dimensional space. After a brief flurry of interest in the late 1800's they became mostly a mathematical curiosity, because many of the things that were done with quaternions could be done more simply with vector analysis. However, in recent years, quaternions have enjoyed a strong revival because they are well suited to problems in astrophysics and astronautics (Kuipers 1999) and three dimensional animation, that are poorly handled by vector analysis. They also play a part in quantum mechanics and general relativity (Stewart 2007).

Quaternions provide an intuitive natural model of movements in three-dimensional space, because the logic of rotations in three-dimensional space is intrinsic in their rules of combination. A quaternion may be interpreted as an axis of rotation, an angular excursion about that axis, and a change in magnitude. Rotations of vectors may be represented by the multiplication of the vectors by quaternions.

Framed Vectors

The other half of the approach introduced here is a method of representing anatomical structures by ordered arrays of vectors, called framed vectors. A framed vector contains vectors that define the location, extension, and orientation of the anatomical structure. The combination of quaternions with framed vectors models the movements of anatomical structures in three-dimensional space. One can literally write down an anatomical description of a structure and use it to compute the movements that may occur.

While this approach may be as precise and detailed as one wants, it also lends itself to more qualitative analysis, because it is so intuitive. A quaternion may be indicated by a gesture. One's thumb is pointed in the direction of the axis of rotation and one's fingers curl in the direction of the rotation about that axis. That gesture captures much of the meaning in the corresponding quaternion.

Orientation

Perhaps the way in which this approach differs most from others is in its treatment of orientation. Anatomical structures are orientable in the sense that one can differentiate a dorsal and ventral surface, a medial and lateral margin, and a proximal and distal aspect. One can tell a right foot from a left foot. That property of the structure is its orientation.

One starts with the observation that anatomical movements are as much about the orientation of the moving structure as they are about the location of the structure. When reaching for a cup, it is equally important that your hand be placed near the cup and that it be oriented so that the fingers can curl about the cup or its handle. It is common practice to roll those two concepts into a single entity, which often leads to confusion or ambiguity. Differentiating them is important, because anatomical movements transform them differently.

The first step is defining orientation in a way that allows one to compute with it. That is accomplished here by creating a set of mutually orthogonal unit vectors that point in anatomically significant directions. Such a set of vectors is called a frame of reference, or often, just a frame. A frame of reference is a component of a framed vector.

Since a frame of reference is a set of vectors, it may be transformed by quaternion multiplication in a manner that precisely models the transformation of a structure's orientation by a rotation. Consequently, we not only model orientation, but also its behavior during movements.

Summary

The approach described here is simple in the sense that there are a few basic concepts that are applied in a consistent fashion. However, it is deep in the sense that it addresses the fundamental properties of space, structure, and movement. It is powerful in that one can easily create an anatomical description that leads directly to computation of the movements of the structure.

On the other hand, it becomes rapidly evident when examining anatomical movement on this level that one rapidly becomes concerned with a difficult analysis that often requires a great deal of concentration to interpret. This approach gives clear and detailed answers that may require time and effort to understand. Three-dimensional diagrams, to aid understanding, often accompany calculations in the text. Fortunately, this approach semi-automatically creates such images. For most people, visual images are easier to understand than sets of equations, therefore, images are used freely in the text. It may be that one of the greatest assets of this approach is that it provides the foundations for creating images of the anatomy and its movements. However, there is constant interplay between the equations and the images.

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