DyAna - FOR 3 DIMENSIONAL ANALYSIS OF HUMAN MOTION

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Introduction

The study of the dynamics of human motion has, until recently, been limited to research in two dimensions. Although three dimensional analyses are more common today, they are generally limited to kinematic evaluations with few studies examining the kinetics of human movement. A complete understanding of the biomechanics of human motion requires an examination of the forces and torques driving the movement. The purpose of this research was to develop a computer program capable of doing a complete dynamic analysis of three dimensional motion of the entire human body while performing aerial skills.

Methods and Procedures

Data collection and reduction.

A 14 segment, rigid link model was used to represent the human body for this research. The 14 segments used in the model were the; trunk, head, neck, and right and left arms, forearms, hands, thighs, legs, and feet. The MIT Human Scale 1/2/3 data of Diffrient et al. (1974) was used to calculate the mass and the location of the center of mass for each segment. The principal mass moments of inertia for each link were calculated by normalizing the data, from Whitsett (1963) using the methods of Dapena (1978).

The motions studied were the tuck jump, split jump and straddle jump and data was collected with two SVHS video cameras operating at 60 fields per second. The endpoints of each segment were then digitized using the Ariel Performance Analysis System. The Direct Linear Transform (DLT) technique was then used to transform the two views of two dimensional coordinates into three dimensional coordinates. These coordinates were then smoothed using a quintic spline and subsequently stored in an ASCII format along with the appropriate body segment parameters. This data file was used as input for the computer program ***DyAna*** which was written in 'C' and developed to perform a three dimensional kinetic and kinematic analysis of the motion.

Coordinate systems, orientation angles and transformations.

The movement of the rigid links in a system in space can be defined in relation to a non-rotating frame or coordinate system common to all of the body segments termed the inertial coordinate system (ICS). It will be defined by a frame consisting of three mutually orthogonal axes x, **y, z** following the 'right hand' convention. The unit coordinate vectors for this system will be given by **i, j,** k. The orientation of any link i in the ICS is defined as the orientation of a frame of reference termed a local coordinate system (LCS) which is fixed to the link. For each link **i** there will be a right handed frame defined by three mutually orthogonal axes x_i, y_i, z_i with unit coordinate vectors given by $\mathbf{i}_i$, $\mathbf{j}_i$, $\mathbf{k}_i$ which as shown by Yeadon(1990) can be defined as: $\mathbf{i}_i$ is parallel to **a**, $\mathbf{j}_i$ is parallel to $\mathbf{i} \times b$, and $\mathbf{k}_i = \mathbf{i}_i \times \mathbf{j}_i$ where **a** is a vector pointing from the proximal end to the distal end of link **i** and b is a vector pointing from the proximal end to the distal end of a link attached at the proximal joint of link **i**. In this study, because of problems caused by digitizing error, $\mathbf{j}_{thighs}$ and $\mathbf{j}_{legs}$ were assigned the values of $\mathbf{j}_{feet}$ and $\mathbf{j}_{hands}$ and, $\mathbf{j}_{forearms}$ were assigned the values of **j** For the head and trunk b was defined as a vector pointing from the left shoulder joint to the right shoulder joint.

The orientation of the local frame with respect to the inertial frame was given by the xyz-convention Euler angles. Knowing the directions of $\mathbf{i}_i$, $\mathbf{j}_i$, $\mathbf{k}_i$ in the ICS Yeadon(1990) shows a transformation matrix which transforms a vector from the coordinates in the ICS to coordinates in the LCS.

Three dimensional kinematic and kinetic analysis

The linear velocity and acceleration of each segment's center of mass in the ICS were calculated using a central difference technique. The angular velocity ω and angular acceleration α in the LCS of any link **i** at any time t were calculated using a finite difference technique.

An inverse dynamics approach was used to perform a kinetic analysis of the human airborne motion. The basic equations for each segment of the system, are given by $\Sigma F_x = ma_x$ $\Sigma F_y = ma_y$ $\Sigma F_z = ma_z$ for the linear motion and $\Sigma M_x = I_{xx}\alpha_x - (I_{yy} - I_{zz})\omega_y\omega_z$, $\Sigma M_y = I_{yy}\alpha_y - (I_{zz} - I_{xx})\omega_z\omega_x$, $\Sigma M_z = I_{zz}\alpha_z - (I_{xx} - I_{yy})\omega_x\omega_y$ for angular motion when kinematics are known in the LCS. These equations were then solved using methods similar to those of Huang, et al.(1983).

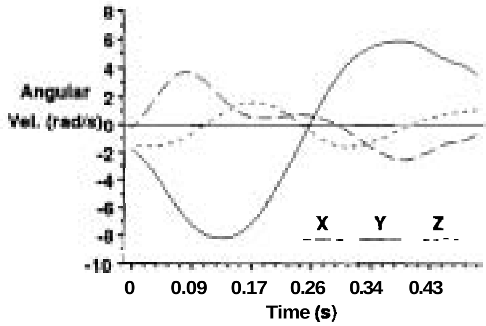
Animation

Routines were also written to allow the program user to view an animation of the human motion from a three dimensional perspective while simultaneously viewing the dynamics results.

Results

DyAna was capable of producing a large amount of data, all of which it is not reasonable to report here, therefore only examples of typical or particularly interesting findings will be reported here.

Figure 1 is an example of the angular kinematics for the right thigh during a tuck jump. The maximum angular velocity found for the thigh in all of the tuck jumps was 11.5 radians/second and the maximum angular acceleration was 208 radians/second^2. These values are similar to the values reported by Huang et al. (1983) for simulated kicking and Putnam(1981) for punting a football, which exhibit similar types of movement of the thigh around the hip joint.



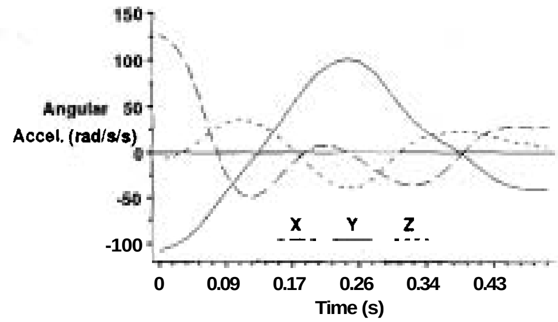


Figure 1 - An example of the angular kinematics in LCS for the right thigh during a tuck jump.

Figure 2 provides examples of the net joint reaction forces calculated for the left leg during a tuck jump. The magnitudes of the forces are slightly less than those found by Zernicke and Roberts (1978) and Huang et al.(1983) in their two dimensional studies of kicking.

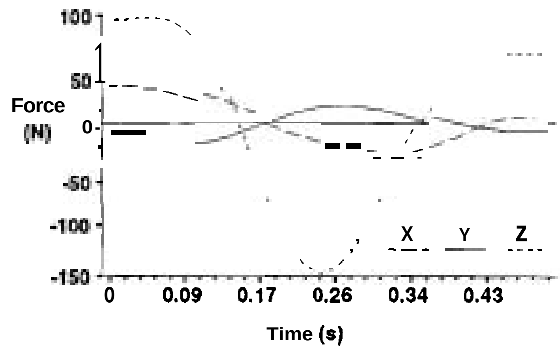


Figure 2 - An example of joint reaction forces for the left leg during a tuck jump.

One of the purposes of this study was to develop a system for three dimensional dynamic analysis of human motion. While the net joint torque values for the tuck and split jumps could have been found, with a reasonable degree of accuracy, using 2 dimensional techniques, the motion of the straddle jump would greatly limit the accuracy of any such data produced for the hip. The final graph of figure 3 illustrates the torque values for the right thigh at the hip joint during a straddle jump as calculated in ***DyAna***. This jump requires the rotation of the thigh about all three inertial axes and this is clearly demonstrated by the net torque values calculated for this trial. The maximum torque values are very similar to those found by Putnam (1981) for punting but about one half of the maximum values found by Huang et al. (1983) for a simulated kick.

Conclusion

In general, the computer program ***DyAna*** was found to work well for doing a three dimensional kinetic and kinematic analysis of human movement for the airborne motions studied. Its best application in the field of biomechanics is in the study of human motion outside of the lab setting, such as in sporting events when subject preparation is not possible. It is presently being implemented in the study of gymnastics and figure skating skills. Future versions of the software will permit inclusion of external forces acting on the body.

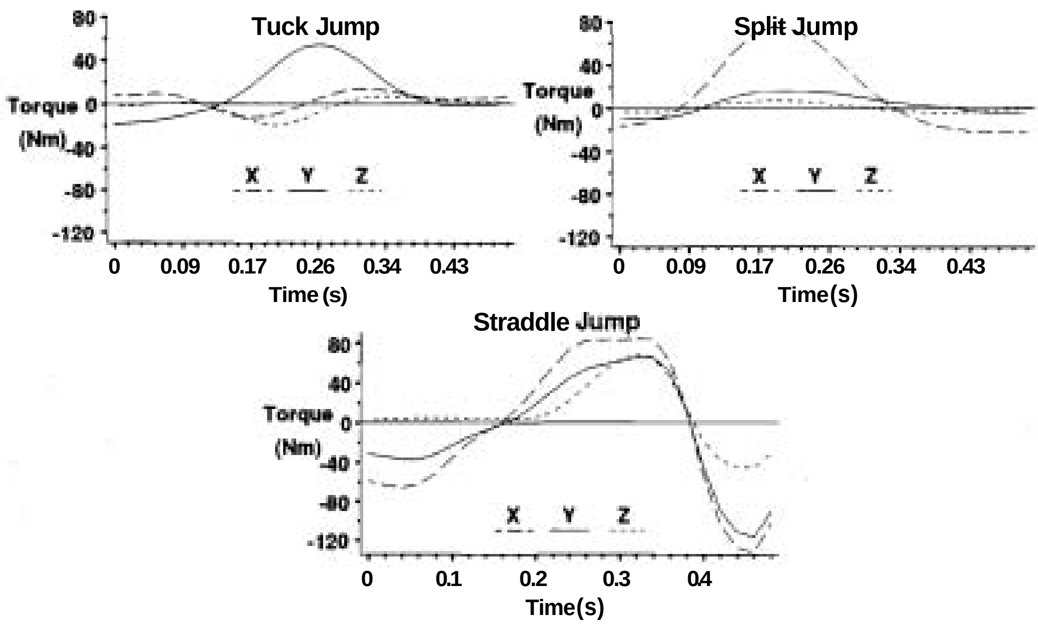


Figure 3 - An example of net joint torques of the right thigh during three different types of jump.

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