# DYNAMIC ANALYSIS ON HUMAN OVERHAND THROWING

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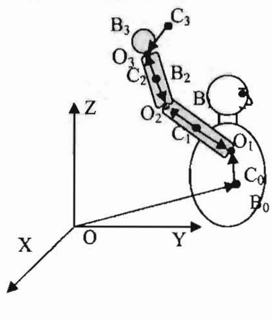
The purpose of this study was to establish a kinetic model to examine the kinetical interactions between segments of upper limb during overhand throwing. A model of three-segment kinetic chain consisting of upper arm, forearm and distal segment was established for kinetic calculation. Using Kane method to get resultant muscular moment. The conclusions can be drawn that the Kane method is effective in describing the upper limb movement and calculating the joint torque. Upper limb movement in Baseball pitching was study by this model and find out some relationships between motion technique and kinetic data.

**KEY WORDS:** kinetic model, kane's dramatic equations, overhand throwing, baseball pitch

**INTRODUTION:** Human movement provides many examples of multi-segment motion, which should be performed by coordinating body segments properly. The motion of multi-segments skills are generally performed in a proximal-distal sequence, which are often described in terms of the linear velocities of the segment endpoints or joint angular velocities. In the example of overhand throwing, it has been observed that the motion starts with a forward angular acceleration of the upper arm while the forearm behind and the hand at last. The proximal segment decelerates while simultaneously the distal segment accelerates. The question is whether the proximal segment is actively decelerated or passively decelerated by joint reaction force from the acceleration distal segment. In the fast overhand throwing movements, baseball pitching is a typical example to create a large linear velocity. The purpose of this study was to establish a kinetic model to examine the joint torque between segments of upper limbs during overhand throwing.

**METHODS:**

**Rigid multi-body model of upper limb and coordinate frame:** A rigid 3-body and 3-joint model of upper limb was established. The rigid body $B_1$ is upper arm, $B_2$ is forearm, and $B_3$ is hand. The model and coordinate system is shown in Figure 1, where shoulder joint is $O_1$, elbow joint is $O_2$, wrist joint is $O_3$. The frame $OXYZ$ is a reference coordinate linked on the earth. The frame $O_0X_0Y_0Z_0$ is a movable coordinate link on human body which $O_0$ on the center of shoulder joint just as $O_1$. The frame $O_iX_iY_iZ_i$ (i=1,2,3) is a movable coordinate frame linked with rigid body $B_i$.



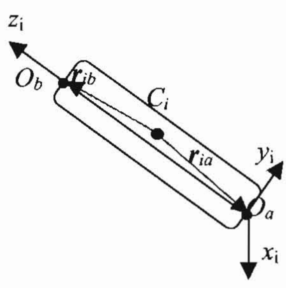




**Figure 1 Kinetic model of human upper limb.**

**Generalized coordinates:** The upper limb of human will move in three dimensions so the freedom degree is 7. $q_r$ (r=1,2,3...7) is the generalized coordinates. The definitions of $q_r$ are in Table 1. $q_r$ describe the position of upper limb (show in Figure 2)

**Table 1 Definition of $q_r$.**

| Generalized coordinates | Around axis | Concerned segment | Segment movement |
|---|---|---|---|
| q1 | X1 | | adduction/abduction |
| q2 | Y1 | Upper arm | Internal/external rotation |
| q3 | Z1 | | Flexion/extension |
| q4 | Y2 | forearm | Internal/external rotation |
| q5 | Z2 | | Flexion/extension |
| q6 | X3 | hand | adduction/abduction |
| q7 | Z3 | | Flexion/extension |

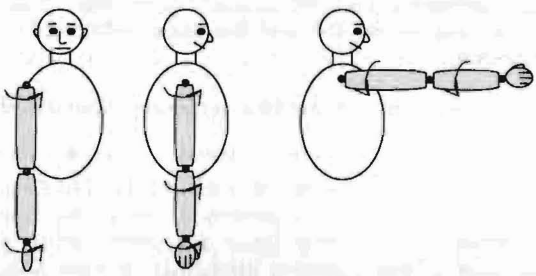


**Figure 2 Generalized coordinates $q_r$ describe the position of upper limb.**

**Dynamic analysis.** Kane's dynamic equations were used to examine the torque between two segments. The main steps for solving this problem with Kane's method are the following. (1)analyze velocity and angle velocity. $\Omega_1$ is the angle velocity of upper arm relative to trunk. $\Omega_2$ is the angle velocity of forearm relative to upper arm. $\Omega_3$ is the angle velocity of hand relative to forearm. Absolute angle velocity of trunk is $\omega_0$, it can be projected to frame $O_1X_1Y_1Z_1$:

$$\omega_{0(1)} = \begin{bmatrix} \omega_{0x}^{*} \\ \omega_{0y}^{*} \\ \omega_{0z}^{*} \end{bmatrix}_{(1)}$$

Absolute angle velocity of $B_i$ is $\omega_i$ (i=1,2,3), where

$$\omega_1 = \omega_0 + \Omega_1, \quad \omega_2 = \omega_1 + \Omega_2, \quad \omega_3 = \omega_2 + \Omega_3,$$

The velocity of shoulder joint ($O_1$) is $v_{01}$, the velocity of center of gravity of each segment are

$$\boldsymbol{v}_1 = \boldsymbol{v}_{O1} + \boldsymbol{r}_{11} \times \boldsymbol{\omega}_1, \quad \boldsymbol{v}_2 = \boldsymbol{v}_{O1} + \boldsymbol{l}_{12} \times \boldsymbol{\omega}_1 + \boldsymbol{r}_{22} \times \boldsymbol{\omega}_2,$$

$$\boldsymbol{v}_3 = \boldsymbol{v}_{O1} + \boldsymbol{l}_{12} \times \boldsymbol{\omega}_1 + \boldsymbol{l}_{23} \times \boldsymbol{\omega}_2 + \boldsymbol{r}_{33} \times \boldsymbol{\omega}_3$$

(2) Select the pseudo-velocity. We select

$$u_1 = \omega_{0x}^{*} + \dot{q}_1 c_2 c_3 + \dot{q}_2 s_3$$
$$u_2 = \omega_{0y}^{*} - \dot{q}_1 c_2 s_3 + \dot{q}_2 c_3$$
$$u_3 = \omega_{0z}^{*} + \dot{q}_1 s_2 + \dot{q}_3$$
$$u_j = \dot{q}_j (j = 4,5,6,7)$$

So the $\dot{q}_r$ can be expressed by pseudo-velocity $u_r$. $\dot{q}_r = \dot{q}(u_r, q_r) \quad (r = 1,2,3 \ldots 7)$

(3) Solve generalized active force $F^{(r)}$ and generalized inertia force $F^{*(r)}$(r=1,2,3…7)

(4) At last the dynamic equation is:

$$\begin{cases} F^{(r)} + F^{*(r)} = 0 & (r = 1,2,3...7) \\ \dot{q}_r = \dot{q}(u_r, q_r) & (r = 1,2,3...7) \end{cases} \quad (r=1, 2, 3...7)$$

The generalized active force $F^{(r)}$ contains joint torque $T_r$, pseudo-velocity $u_r$. There are 14 equations altogether, so these equations can solve 14 unknown variables. The joint torque $T_r$ can be solved out if the movement $q_r$ are known.

Six elite baseball pitchers were selected as subjects for this study. Qualisys motion capture system (six Proreflex MCU digital cameras) set as 240Hz was used to record the pitching performance and to calculate the kinematic date of upper limb movement ($q_r$). Therefore, $u_r$ and $T_r$ can be solved by Kane's dramatic equations.

**RESULT AND DISCUSSION:** The results were shown as Figure 3 to Figure 5. Figure 3 shows joint torque of shoulder during pitching.

Figure 3 shows, during the first half period of the throwing motion, the resultant shoulder torque is small, but enough to keep the shoulder joint correctly positioned. And the torque applied to the upper arm is small when the upper arm is in a horizontal abducted position. Significant shoulder-flexion torque could be observed when the upper arm is adducted horizontally in an accelerating speed, while extension torque appeared at the end of the horizontal adduction, and reaches its maximum at the release point.

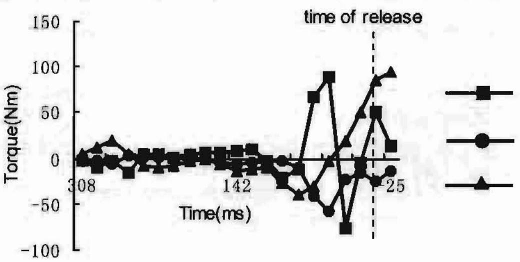



**Figure 3 Joint torque of shoulder during pitching.**

The torque pattern of elbow joint is shown in Figure 4. During the first half period of the throwing motion, elbow flexor muscles create flexion torque to keep the elbow joint flexed, and the following elbow extension is the effect of contracting elbow extensor muscles. Elbow extension torque decreases very fast before ball release, and turns into elbow flexion torque at the release point.

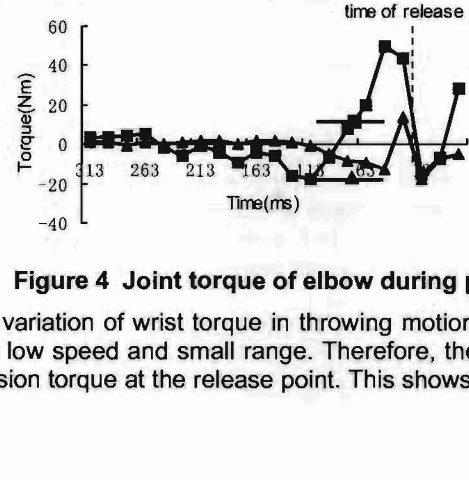



**Figure 4 Joint torque of elbow during pitching.**

Figure 5 shows the variation of wrist torque in throwing motion. Although wrist flexion could be observed, it is in low speed and small range. Therefore, the wrist flexion torque is small, and turns into extension torque at the release point. This shows more control is applied to the wrist.

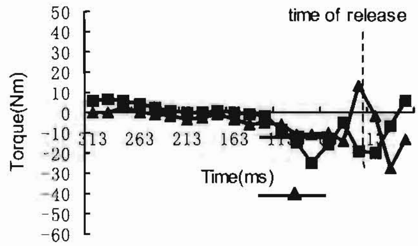



**Figure 5 Joint torque of wrist during pitching.**

**CONCLUSION:** There are several conclusions according to this research.

(1) A rigid multi-body model with 3 segments and 7 degrees of freedom is established by simplifying the three segments of the upper limb. It is proved that the model is feasible. It can be used to simulate the movement and function of the upper limb.

(2) It is proved that the Kane method is effective in describing the upper limb movement and calculating the joint torque.

(3) Through calculating and analyzing the torques on the three joints of upper arm, the relationship between the torques and movement is preliminarily revealed.

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