THE HUMAN FEMUR MOTION AND TORQUE IN HIP JOINT

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Abstract

Normal human locomotion requires a complex interactive control between multiple limb and body segments that work congruently to provide the most shock-absorbing and energy-efficient forward movement possible. The kinematics model considers the hip joint as a superposition of 3 independent, orthogonal and simple revolute joints and the knee joint as a simple revolute one. Concerning dynamic model, the study's aim was to represent the active forces and moments needed in joints in order to assure the motion by considering the role of muscles at every phase, as well as the human leg's mass distribution.

Key Words: **Femur, joint, kinematics.**

1. Introduction

The paper studies the femur bone as a part of human lower limb. Concerning kinematics model, the human femur is considered as an articulated body between the hip joint and the knee one. The kinematics modeling was performed by using Denavit-Hartenberg robotics convention. The dynamic behavior study followed to estimate the torque in hip joint. For that, the original Bio&Soft program was created which is able to compute all forces and moments in the human locomotors apparatus joints.

2. Motion modeling

The kinematics model considers the hip joint as a superposition of 3 independent, orthogonal and simple revolute joints and the knee joint as a simple revolute one (figure 1). This model is concordant with anatomic knowledge about different possible motions inside femur human joints.

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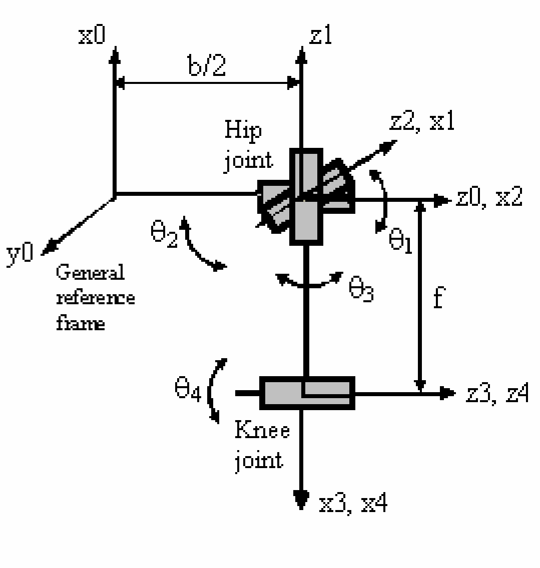

Fig. 1. Kinematics femur model

Denavit-Hartenberg convention was applied and, as a result, the Table 1 was obtained and the correspondent transfer matrices too:

Table 1

Joint	q_i	α_i	l_i	d_i
1	θ_1	-90°	0	0
2	θ_2	-90°	0	0
3	θ_3	90°	f	0
4	θ_4	0°	0	0

$$^0T_1 = \begin{bmatrix} \cos\theta_1 & 0 & -\sin\theta_1 & 0 \\ \sin\theta_1 & 0 & \cos\theta_1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad ^1T_2 = \begin{bmatrix} \cos\theta_2 & 0 & -\sin\theta_2 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^2T_3 = \begin{bmatrix} \cos\theta_3 & 0 & \sin\theta_3 & f\cdot\cos\theta_3 \\ \sin\theta_3 & 0 & -\cos\theta_3 & f\cdot\sin\theta_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad ^3T_4 = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & 0 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

where: θ_i *(i =1, ...,4)* are joint variables and f is the femur length.

The kinematics equations, describing femur motion with respect to the general reference frame, are given by multiplying the transfer matrices (1). So, the general matrix:

$$
{}^{0}G_4 = {}^{0}T_1 \cdot {}^{1}T_2 \cdot {}^{2}T_3 \cdot {}^{3}T_4 =
$$

$$
= \begin{bmatrix} c1(c2c3c4 - s2s4) + & c1(-c2c3s4 - s2c4) - & \multirow{2}{*}{c1c2s3 - s1c3} & \multirow{2}{*}{f(c2c2c3 - s1s3)} \\ + s1s3c4 & - s1s3s4 & & \\ s1(c2c3c4 - s2s4) - & s1(-c2c3s4 - s2c4) + & \multirow{2}{*}{s1c2s3 + c2c3} & \multirow{2}{*}{f(s1c2c3 + c1s3)} \\ - c1s3c4 & + c1s3s4 & & \\ -(s2c3c4 + c2s4) & s2c3s4 - c2c4 & -s2s3 & -f \cdot s2c3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)
$$

where there were noted: $\cos\theta_i = ci \qquad \sin\theta_i = si \qquad i = 1,\ldots,4$.

The kinematics equations were written in order to model the femur lower extremity motion (into knee joint) with respect to the fixed reference frame. By considering a medium size femur f = 45 cm of length and imposing the anatomic limitations to angles θ_1, θ_2 and θ_3, the global displacement of the origin of $x_4\ O_4\ y_4\ z_4$ was calculated with respect to the origin of the fixed reference frame (figure 2).

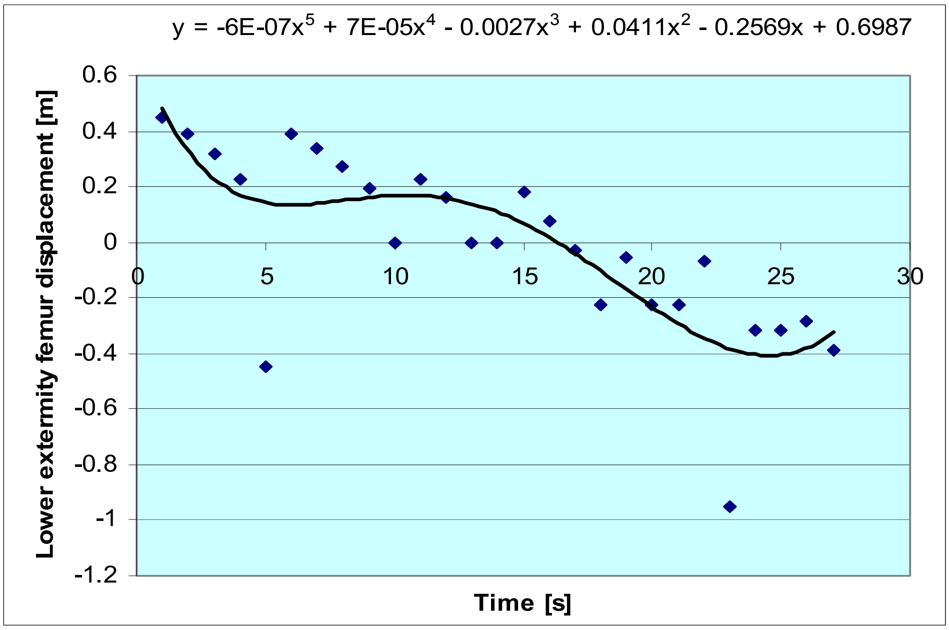

Fig.2. Lower extremity femur displacement conformably to the kinematics model

There were used the values of the expressions in the last column of general matrix (2) for the first quarter of a pace (the femur motion from the vertical position to forward). For the second quarter of the pace (the femur motion from extreme forward position during walking, to the vertical one) the curve will be symmetrical with respect to the vertical passing through the value of 28 s (figure 3). For the two last quarters of the pace, the curve will be symmetrical with respect to the vertical axis passing through the value of 56 s.

It is represented in figure 2 even the analytical function modeling the curve described by the lower extremity of the femur during the first quarter of the walking pace. It was represented by using the R-squared value of 0,619.

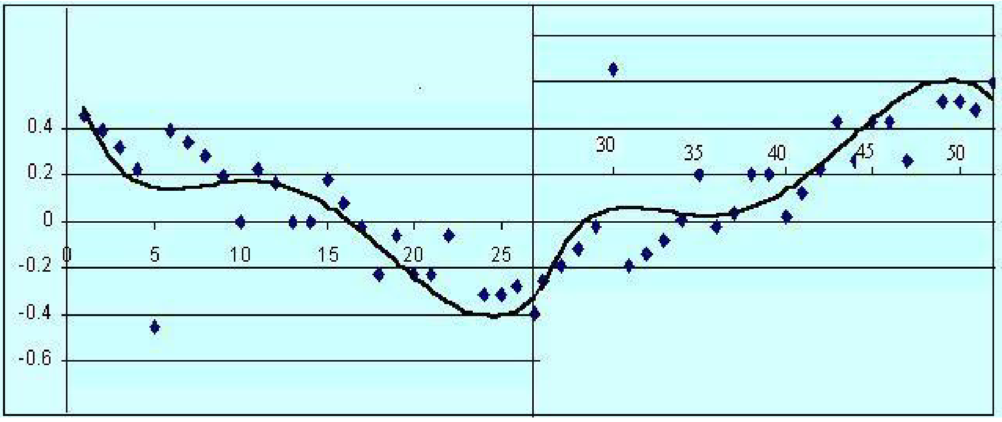

Fig.3 Lower extremity femur motion during a half walking pace

For the other parts of the walking pace, the analytical function modeling the curve could be estimated on the same way.

3. Dynamic torque in hip joint

Concerning dynamic model, the study's aim was to represent the active forces and moments needed in joints in order to assure the motion by considering the role of muscles at every phase, as well as the human leg's mass distribution.

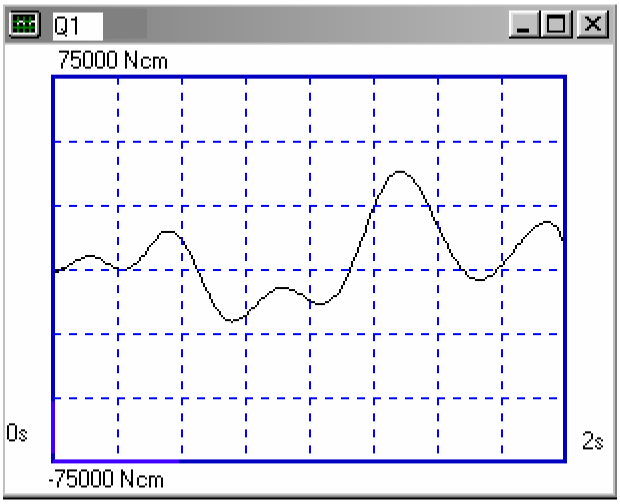

Fig.4 Generalized force (moment) moving the femur around O_1z_1 axis

The created Bio&Soft program, created in Visual Basic 4.0, was used to compute the forces at each pace phase, as function of magnitude, insert points positions and direction of muscles. By reducing these forces with respect to the reference frame placed in each joint, the active torques in joints were obtained. A simplified model of human lower limb was adopted [1] and for this one, by using 2'nd degree Lagrange's equations the generalized forces (moments) in joints were calculated.

For example, in figure 4 it is represented an image capture of Bio&Soft dynamic analyze the active moment Q_1 turning the femur around the O_1z_1 axis in the hip joint. It was computed by using the 2'th degree Lagrange's equations system, written for the femur as a rigid body in figure 1. By combining, as a vectorial sum, the three moments acting in hip joint, the graphical representation of the resultant moment of three orthogonal ones is obtained in figure 5.

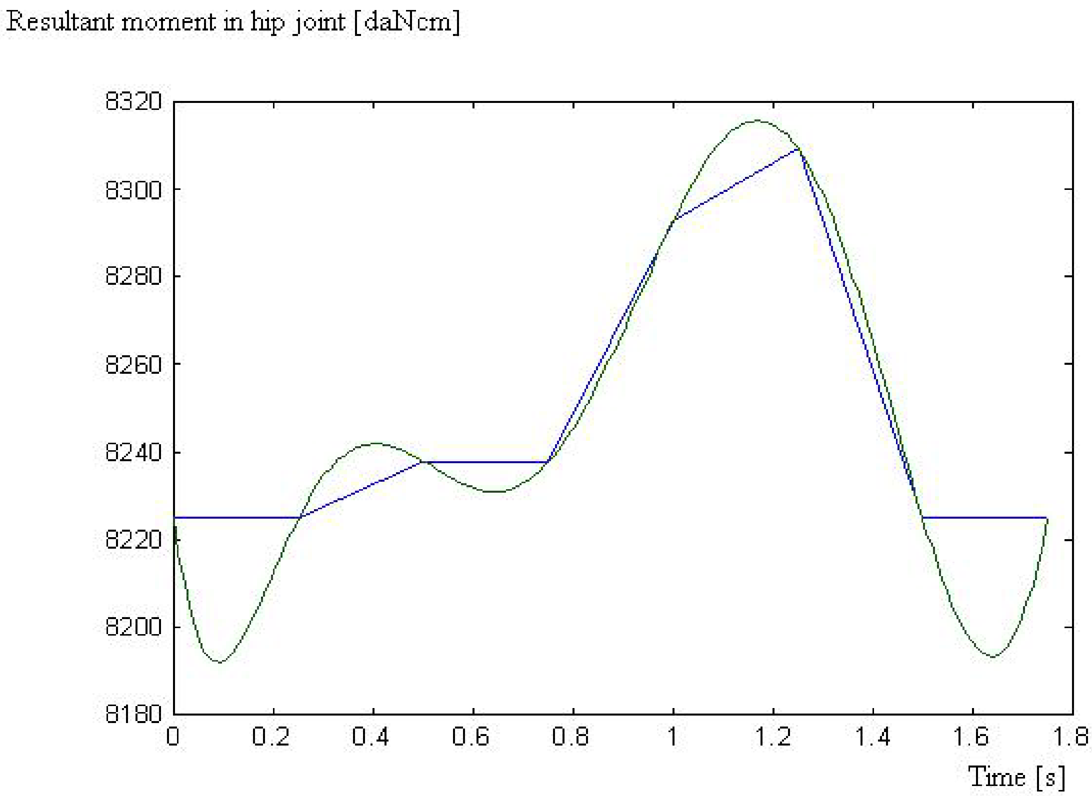

Fig.5 Resultant moment in hip joint during a walking pace

The numerical values got by using Bio&Soft were plotted by using MatLab as follows:

```
x = [0 0.25 0.5 0.75 1 1.25 1.5 1.75];
y = [51735.05 51735.05 52560.56 52562.56 56687.44 58381.86 51735.05 51735.05];
c1 = polyfit(x,y,7);
x1 = 0:.01:1.75;
y2 = polyval(c1,x1);
plot(x,y,x1,y2);
```

4. Conclusions

Normal human locomotion requires a complex interactive control between multiple limb and body segments that work congruently to provide the most shock-absorbing and energy-efficient forward movement possible. Gait characteristics are influenced by muscle strength, dynamic range of motion, and shape, position and function of numerous neuromuscular and musculoskeletal structures, as well as, the ligamentous and capsular constraints of the joints. The primary goal is energy efficiency in progression using a stable kinetic chain of joints and limb segments that work congruently to transport the passenger unit forward.

Clearly, for a simple mechanism such as the RR arm, using DH is a big overhead as compared to simple trigonometry. But for complex mechanisms, DH is far easier to automate. Also, once the frames are fixed and the parameters identified, it is easy to find the relationship between any two frames on the mechanism. Also, the DH parameters are an easy way of completely specifying the mechanism. We will see more of DH in future classes.

5. References

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