THREE-DIMENSIONAL BIOMECHANICAL ANALYSIS OF THE TRUNK AND UPPER EXTREMITY DURING WHEELCHAIR PROPULSION WITH CONSIDERING THE EFFECT OF MUSCLE FORCES

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INTRODUCTION

The number of wheelchair users continues to increase, but limited research has been conducted with respect to the kinetics or wheelchair propulsion. In many studies, it is mentioned, most paralyzed patients suffer from shoulder pain. This problem is significantly caused by the forces and moments forcing upon the upper extremity and trunk during wheelchair propulsion. Therefore, establishing an investigation leading to optimal wheelchair/user match to facilitate effective and safe activity is essential. In this research, our aim is obtaining the forces and moments at the joints of the user during wheelchair propulsion. Therefore, by using the concepts of biomechanic and robotics, the trunk and upper extremity are modeled as a 3-D linkage system with eight degrees of freedom which representing the trunk, arm, forearm and hand. In this model the most important muscle forces of the trunk and upper extremity in wheelchair propulsion are forcing on the linkage system [Van der Helm,1991].

METHODS

The kinetical analysis of the model has been developed, by using the Newton-Euler equations to give the forces and moments at the joints. During wheelchair propulsion, in order to find the forces and moments in the given model ,the information which should be obtained from laboratory equipment are needed. These information are as followings: Kinematics data of the upper extremity and body joints, The forces and moments acting on the hand and effective muscle forces in wheelchair propulsion during driving cycle.

Kinematical data acquisition- In this research regarding to the existing facilities in Iran among the usual methods like electrogoniometery, Cinematography and Sonic digitizers, the Videography is applied.To start the acquisition, some markers are attached to the body and upper extremity. Then by the aid of two perpendicular video cameras, the pictures of the subject are taken and then would be transferred to a PC.The primary measurements will be done by the PC and finally in order to obtain accurate dimension, some equations are calculated which gives real values due to reference frame.

$$
\begin{aligned}
Z &= (Z_r.L_r.Z_l)/(F_r.Z_l + Z_r.Y_l)\\
X &= X_r(L_r - (Y_l.L_l)/F_r)/(F_r(1-(X_r.Y_l)/(F_r.F_l)))\\
Y &= Y_l(L_l - X)/F_l
\end{aligned}
\tag{1}
$$

L_l is the distance between the reference frame and the left camera l_r is the distance between the reference frame and the right camera, F_r and F_l are virtual lengths which are obtained by some standard tests. X_r and Z_r are the coordinates in the right camera. Z_l and Y_l are the coordinates in the left camera.

The forces and moments acting on the hand- These values are taken by a special wheelchair equipped with a force transducer. Because of not having necessary facilities, the forces and the moments are applied from available references [Veeger,1992],[Moeinzadeh,1990].The coordinates of the origin and insertion of the muscle and the values of muscle force are taken from available references [Vander Helm,1991].

Kinematics of 3-D mathematical model-By using the usual methods in the robotics and biomechanic [Craig,1986],linear velocity and acceleration and angular velocity and acceleration are obtained.

$$\begin{aligned}
{}^{i+1}\omega_{i+1} &= {}^{i+1}_{i}R\,{}^{i}\omega_i + \dot\theta_{i+1}\,{}^{i+1}\hat{Z}_{i+1} \\
{}^{i+1}\dot\omega_{i+1} &= {}^{i+1}_{i}R\,{}^{i}\dot\omega_i + {}^{i+1}_{i}R\,{}^{i}\omega_i \times \dot\theta_{i+1}\,{}^{i+1}\hat{Z}_{i+1} + \ddot\theta_{i+1}\,{}^{i+1}\hat{Z}_{i+1} \\
{}^{i+1}\dot{V}_{i+1} &= {}^{i+1}_{i}R[{}^{i}\dot\omega_i \times {}^{i}P_{i+1} + {}^{i}\omega_i \times ({}^{i}\omega_i \times {}^{i}P_{i+1}) + {}^{i}\dot{V}_i] \\
{}^{i}\dot{V}_{ci} &= {}^{i}\dot\omega_i \times {}^{i}P_{ci} + {}^{i}\omega_i \times ({}^{i}\omega_i \times {}^{i}P_{ci}) + {}^{i}\dot{V}_i
\end{aligned} \tag{2}$$

In this equations ω is the angular velocity, R is rotational matrix ,θ is rotational angle, V is linear velocity and P is the link length, V_C is the linear velocity of the center of mass for the link and P_C is the distance between the center of mass and link's frame.

The method used for obtaining joint angles of the model- The angle joints of the model are calculated by using inverse kinematics' method and solving nonlinear equations.

Kinetic of 3-D mathematical model- In this section due to robots dynamic by using Newton-Uler equations a classic method is used.

$$\begin{aligned}
F_i &= M\dot{V}_{ci} \\
N_i &= {}^{ci}I\dot\omega_i + \omega_i \times {}^{ci}I\omega_i
\end{aligned} \tag{3}$$

I ,is the moment of inertia and M is the mass, ci defines a frame which is in the center of mass. Considering a free body diagram of a sample link and equilibrium equations for moments and forces, some equations are obtained which gives moments and forces on the joints.

$$\begin{aligned}
{}^{i}F_i &= {}^{i}f_i + f_{mi} - {}^{i}_{i+1}R\,{}^{i+1}f_{i+1} \\
{}^{i}f_i &= {}^{i}_{i+1}R\,{}^{i+1}f_{i+1} - F_{mi} + {}^{i}F_i \\
{}^{i}N_i &= {}^{i}n_i + n_{mi} - {}^{i}_{i+1}R\,{}^{i+1}n_{i+1} - {}^{i}P_{ci} \times {}^{i}F_i - {}^{i}P_{i+1} \times {}^{i}_{i+1}R\,{}^{i+1}f_{i+1} \\
{}^{i}n_i &= {}^{i}_{i+1}R\,{}^{i+1}n_{i+1} + {}^{i}P_{ci} \times {}^{i}F_i + {}^{i}P_{i+1} \times {}^{i}_{i+1}R\,{}^{i+1}f_{i+1} - n_{mi} + {}^{i}N_i
\end{aligned} \tag{4}$$

F, is the equivalent force which acts on the center of mass in the link, f is the force which acts on the link by the next link. N, is the equivalent moment in the center of mass and n is the moment in the link's frame. F_m and N_m are for the muscles. In calculating the tensor of inertia for the link's of the model around their of mass, each of them are considered as a similar geometrical volume to themselves. The user is informed to propel a specific wheelchair at a predefined velocity. Meanwhile, simultaneous output of the experimental set-up for kinematics analysis, and the applied forces and moments to the user's hand, is fed into a computational programs. This program has been written for kinetical analysis of the model.

RESULTS

Having the mass, the center of mass and the moments of inertia of the user's trunk, arm, forearm and hand, the program which has been written for kinetical analysis, yields to give the forces and the moments at the joints vs. time.

Regarding this method, the forces and the moments in the joints of the upper extremity can be calculated. This method can be used for determining the state in which these forces and moments are minimized. In this research the height of the seat is the variable parameter. Here the graphs of the joint forces (Fig.1) and the joint moments (Fig.2) which are obtained from equations number four, presented as a sample. For obtaining the more exact results, the shoulder complex should be considered in the analysis of the model.

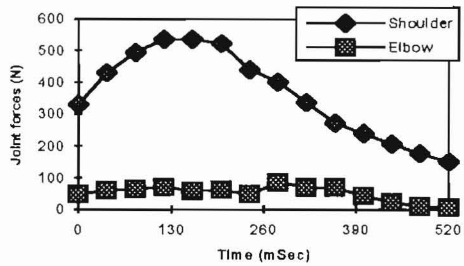

Fig. 1: Joints forces

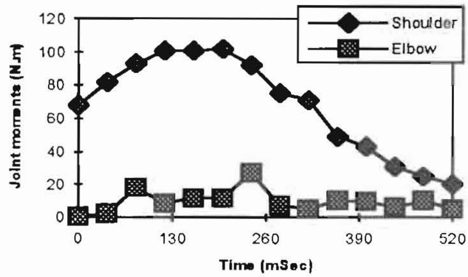

Fig. 2: Joints moments

CONCLUSION

To obtain an optimal wheelchair/user match one can change the geometrical dimensions of the chair such as rim diameter, height and placement of the seat, and also propulsion technique and determine their effects on the forces and moments occurring at the joints. Meanwhile, we can use this method in sport for athletes with disabilities.

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