Süleyman Demirel Üniversitesi
Mühendislik Bilimleri ve Tasarım Dergisi
2(3),ÖS:BiyoMekanik2014, 185-188, 2014
ISSN: 1308-6693

Suleyman Demirel University
Journal of Engineering Sciences and Design
2(3),SI:Biomechanics, 185-188, 2014
ISSN: 1308-6693

THE IMPLEMENTATION OF TORQUE GENERATORS ON A HUMAN RIGID BODY MODEL

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Keywords
Torque Generator
Simulation
Human Rigid Body Model
Forward Dynamics
Sports Biomechanics

Abstract

Simulations of human movements are widely used in many fields such as sports biomechanics, robotics, clinical studies, and entertainment (film / video game) industry. To simulate different scenarios and answer 'what if' questions the model would use forward dynamics principles. The actuator elements such as individual muscles or torque generators supply input to the system whereas motion of the model is the output. In the literature, torque generators are used in simulations of sports movements where information on muscle group level is generally sufficient. Torque generators are hypothetical elements attached to the joints and generate torque around that joint. The amount of torque generated represents the torque created by the muscles passing through that joint. Maximum possible torque values are estimated in torque generators. Therefore, these values are multiplied by muscle activation which has values between 0 (no activation) and 1 (full activation). In this study, torque generators were implemented on a human rigid body model which was presented in the literature. The kinematic model was developed for platform diving and consists of six rigid segments. The actual performance was a forward two and a half somersault dive from 10 m above. The performance was recorded and joint angles in the sagittal plane were calculated, previously. 5 torque generators (shoulder, elbow, hip, knee, ankle) are added to the model. At each torque generator, torque values are calculated using the joint angle at that instant. The equation of motion is solved with the torque value estimated in the torque generator and joint angle for the next instant is calculated. Then, it is sent to the torque generator to estimate new torque value. This process repeats during the entire simulation. Once the matching of the actual performance is achieved the model with the torque generator can be used to simulate different scenarios. For example, the effect of the change in the muscle activation levels/timings on the performance can be analyzed or an optimum technique can be sought to increase the performance and reduce the risk of injury. The same methodology can be applied to other models developed for different sports movement.

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1. Introduction

Computer simulations of human movement may be used to understand the dynamics of a previously recorded motion or to make predictions about possible outcomes of hypothetical motions. Especially, when the motions in consideration are not suitable or not practical for experimental analysis, computer simulation models may be the best alternative for the analysis of the motion. With the advancement of computer technology in the recent decades, simulations may be run in a very short amount of time and more complex models may be developed when necessary. As a natural consequence of these, computer simulation models of human movement are used extensively in many different fields such as sports biomechanics, robotics, clinical studies, and entertainment (film / video game) industry.

A model, which is the simplified representation of the human body or body segments, has to be developed for computer simulations. This model must represent the behaviour of the human body adequately considering the motion to be simulated and the 'what if' questions to be answered at the end of the simulation. For this reason, realistic input data should be used and realistic values of the model parameters should be determined. In addition, the model has to be evaluated or validated, otherwise the results of the simulation would not reflect realistic results.

Forward dynamics computer simulation models can be used to predict what might happen in different conditions and therefore help to gain an understanding of the dynamics of the motion. It may also be used for optimisation by running thousands of simulations in a few hours or days. In forward dynamics models the driving or actuating forces are specified and the aim is to determine the corresponding motion. In sports biomechanics, this type of models used to analyse a particular sports movement for improving performance and/or injury prevention. Depending on the complexity of the model, torque generators or individual muscles may be used as driving elements of the model.

If understanding of the motion at muscle groups level (rather than individual muscles) is sufficient torque generators can be used. These are hypothetical elements attached to the joints and generate torque around that joint. The amount of torque generated represents the torque created by the muscles passing through that joint.

Although it is not very common in the literature, forward dynamics models with torque generators were used to determine optimum performance for given conditions. Kong et al. (2008) studied on optimum take-off technique for maximum forward rotation in springboard diving. They used an eight-segment model with five torque generators. King and Yeadon (2004) used their five-segment model with four torque generators to maximise somersault rotation in tumbling. Wilson et al. (2008) investigated the effect of approach conditions and take-off technique on optimum performance in high jump. Similar to Kong eight-segment model with five torque generators were used in this study. Although most of the models in the literature are planar a 3D model of human arm was developed to investigate the loadings at the wrist and elbow during tennis backhand groundstrokes for a better understanding of tennis elbow (Kentel et al, 2011). In this study, seven segments were used including the tennis racket. A total of seven torque generators were used at shoulder (3), elbow (2) and wrist (2) joints.

The aim of this study is to introduce the role of a torque generator on a forward dynamics simulation model and present the implementation of a torque generator on a human rigid body model. For a sports movement, performance, inertial, and strength data are necessary for this purpose. Therefore, a previous study providing performance data of platform diving (Koschorreck and Mombaur, 2012) was selected. Torque generators were added to the model presented in the study to drive the model using forward dynamics principles. The implementation of the torque generators and the benefits of using them will be elaborated and discussed in detail in the following sections.

2. Torque Generators

The actual performance presented in the study of Koschorreck and Mombaur (2012) is a forward two and a half somersault dive from 10 m above. The performance was recorded and joint angles in the sagittal plane were calculated. A six-segment planar kinematic model was used and five torque generators (shoulder, elbow, hip, knee, ankle) were added to the model (Fig. 1). The torque generators were modelled as a contractile component and a series elastic component adapted from a previous study. (Kong, 2005).

Torque generators may be referred to rotational forms of Hill-type muscle models which are linear. The total length of a muscle-tendon complex is the sum of the muscle fiber (contractile component) length and the tendon (elastic component) length. Analogous to this joint angle is the sum of muscle angle (contractile component) and tendon angle (elastic component). Each torque generator has extensor and flexor parts that act in opposite directions representing agonist and antagonist muscle action. The net torque at that joint is the algebraic sum of the flexor and extensor torque.

Extensor and flexor torque values are calculated using the muscle angle at that instant and torque-strength parameters. These parameters can be obtained by using an isovelocity dynamometer and can determine the maximum voluntary torque that could be produced at a joint as a function of angle and angular velocity (King and Yeadon, 2002).

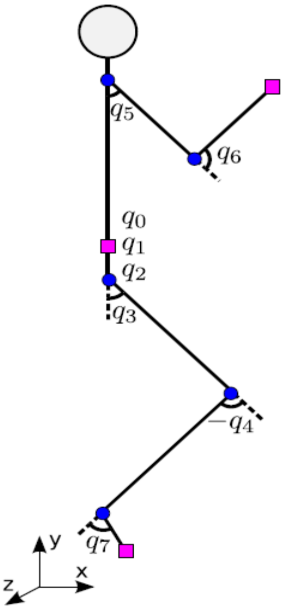

Figure 1. Kinematic model presented by (Koschorreck and Mombaur, 2012) Torque generator locations are shown with blue points.

Using the torque-strength parameters maximum flexor/extensor torque at a joint can be calculated. This maximum torque corresponds to full activation of the muscle group. Therefore, maximum torque values are multiplied with an activation profile which represents the change in the activation of the muscle group as a function of time. In general, the activation profiles are different for flexor and extensor parts of a torque generator. These profiles are parameterized such that only a few parameters represent the whole activation profile throughout the simulation. The product yields the estimated flexor/extensor torque at the joint. Since contractile components and elastic components are in series, the estimated torque at the contractile component is equal to the torque at the elastic component. This equality is the fundamental equation of the torque generators (Eqn 1). The elastic component may be treated as a torsional spring and the torque at the elastic component would be the product of the torsional stiffness of the tendon and the tendon angle (King and Yeadon, 2002).

$$T_{con}(\omega_m, \theta_m) * a(t) = T_e = k_t * \theta_e \qquad (1)$$

3. Methods

The motion of the torso is assumed to be known. The time histories of the position of the centre of gravity of the torso and the orientation of the torso are used to drive this segment kinematically. In order to have a smooth motion, splines were fit (Wood and Jennings, 1979) to the discrete time history data provided. Using splines keep the magnitudes of the first and second derivatives at a reasonable range.

The mass and moment of inertia of each segment as well as the location of the centre of gravity with respect to the proximal joint are provided. So these inertial data used directly in this study. Using the free body diagrams of each segment dynamic equilibrium equations were written considering the inertial forces and torques. The forces at the joints were eliminated and the remaining five equations of motion were written in the following form:

$$[A]\{\ddot{\emptyset}\} + [B]\{\dot{\emptyset}^2\} + \{T\} = \{C\}$$

Where $\{\emptyset\}$ are the absolute orientations of the segments and $\{T\}$ are the net torques at the torque generators.

The torque-strength parameters are not available for the subject used. For this reason, data from another subject doing similar diving performances (Kong, 2005), were used.

The simulation model can be separated into two interacting parts: muscular and mechanical. The muscular part calculates the net torque values at each torque generator and the mechanical part solves the equation of motion for the rigid body model.

The input to the muscular part and also to the overall simulation model is the activation profile parameters. In addition, joint angle value is transferred from mechanical part. At each time step, using fundamental equation for torque generators the net torque is calculated and then transferred to the mechanical part. Moreover, the muscle angle for the next time step is estimated with fourth order Runge Kutta method.

The mechanical part uses the net torque values calculated in the muscular part and estimates the joint angle and the joint angular velocity for the next time step by solving equations of motion with fourth order Runge Kutta method. The joint angle is then transferred to muscular part. This process repeats during the entire simulation and motion of the rigid body model is obtained.

Both parts of the simulation is run numerically with MATLAB. For more complex models 3D models the mechanical may be run with another software package such as MSC.ADAMS. In that case, muscular part may have to be run with a user written subroutine in the software package used.

At the end of the simulation the motion of the model is calculated corresponding to the activation parameters of the torque generators. Optimum parameters and therefore activation profiles are obtained by matching the simulation result and the actual performance. This matching process may be done using different algorithms. In this study, simulated annealing algorithm is used for its capability to find overall extremum points without sticking to the local ones (Goffe et al., 1994).

4. Discussion and Conclusion

This study is now at the matching stage. Once the matching of the simulation results and the actual performance is done, the activation profiles at each torque generator is determined. Using these activation profiles with different initial conditions and/or variables yields the resulting motion. By this way, many different scenarios can be applied to the model. Moreover, by perturbing the activation parameters an optimum performance may be found as in the previous studies in the literature.

One of the main advantage of using torque generators is to have an understanding of the motion at the muscle group level. Although, net torques at the joints drive the model, the flexor and extensor torques at any instant is known, separately. Considering the maximum loading capacity of the muscle groups this information may bring additional insight for injury prevention. One difficulty in using torque generators is the requirement of the torque-strength parameters. However, if an isovelocity dynamometer is available, with the methodology expressed in literature (King and Yeadon, 2002) these parameters can be obtained.

When compared with the individual muscle modelling, torque generator yields an overall effect of the muscle groups. If not a group but an individual muscle is in the focus of the study, using individual muscles in the model would be the correct choice. Yet, these models are more complex and therefore requires more effort and time on the development and computational stages of the model.

In conclusion, torque generators has a moderate complexity and can be seen as an intermediate step between simple models and individual muscle models. Using torque generators in forward dynamics simulations may be a good alternative when information on muscle group level is sufficient.

Acknowledgements

The authors would like to thank Mr. Atakan Üresin and Mr. Çağrı Kızıltan for their contribution.

Conflict of Interest

No conflict of interest was declared by the authors.

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