The effects of solution techniques on the results of the simulation of human motion

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Abstract

Computer simulations of human movements are used for understanding the dynamics of the motion. These simulation models using individual muscles or torque generators can be separated into two parts as the dynamics of the body segments and the muscular mechanics part. The solution of the governing equations for these parts is necessary for the simulation. In this study, two different solution techniques will be compared and discussed. The first technique includes the solution of each part separately whereas all equations solved simultaneously in the second technique. In the first technique, the solutions can be obtained with relatively less computational effort but in the second technique more accurate results are expected. The comparison of the results will show whether the improvement in the accuracy worth the increase in the computational effort. As a result, a particular solution technique can be proposed to all current and forthcoming studies.

Keywords: **Computation, biomechanics, motion analysis, simulation modelling**

Introduction

Computer simulations of human movements are used for understanding the dynamics of the motion. In general, a detailed information is obtained from the simulations at a level where no direct measurement is possible. In the literature, there are many examples of simulation models with different complexity level using different methods. The most common methods for the modelling of the human motion include individual muscles or torque generators as actuators of the model. These elements represent the effect of force/torque generated at the muscle fibres. For example, Anderson and Pandy [1] developed an individual muscle model to simulate walking whereas Kentel et al. [2] developed a model with torque generators for simulating backhand ground strokes in tennis.

The models that use individual muscles or torque generators can be separated into two parts as the dynamics of the body segments and the muscular mechanics part causing the force or torque generation. These parts are directly related to each other and have to be considered together during the simulation. Each part has their own modelling structure but have common variables that affect both parts. The dynamics of the body segments simply deals with the motion of the body using the equation of motion. On the other hand, muscular mechanics part deals with the amount of force/torque generated due to muscle fibres.

The simulation of the human motion depends on the solution of the differential equations relating the variables in each part. The difficulty arises on how to solve these equations since they have common variables. No explicit solution of these equations were present in the literature but two possible ways of solutions may be used. As a first technique, the parts solved separately at each integration step using the data transferred from the other part. In the second technique, all equations are solved simultaneously.

This study focusses on the effects of these two ways of solution techniques on the results. Although the second technique promises more accurate results, the computational effort would be higher. By analysing a sample human motion such as dumbbell curl, this study investigates whether the improvement in the accuracy worth additional computational effort. The results of both techniques are compared and the difficulties as well as advantages of both techniques are discussed

Model Development

This study focusses on the solution technique rather than the motion itself. Therefore, a simple and realistic motion could be selected for the computer simulation. For this purpose, a planar 5 kg dumbbell curl is used. The upper arm is assumed to be fixed and there is no relative motion at the wrist joint. In short, only one segment (forearm and hand) is moving about the joint (elbow) on the sagittal plane. The free body diagram of the forearm with the weight can be seen in Fig. 1. The equation of motion using the free body diagram is given in Eq. (1).

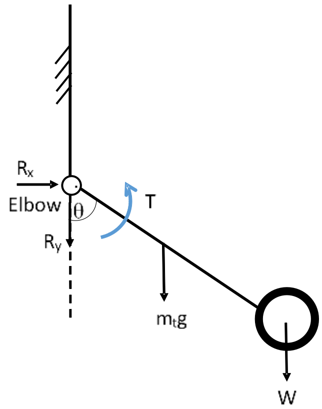

Figure 1. Free body diagram of the forearm with the weight

$$T\text{-}\ I_E\,\ddot{\theta}\text{-}m_t\,g\ l_1\,sin\theta\ \text{-}\ W\,l_2\,sin\theta \qquad (1)$$

As the actuator of the model, a single torque generator located at the elbow joint is used. The anthropometric parameters of the forearm and the torque-strength parameters of the muscles are obtained from the literature [3]. The torque generator represents the moment effects of all muscle fibres going through the elbow joint. It has two separate units each corresponding the flexor and extensor muscle groups for agonistic and antagonistic action. The algebraic sum of the flexor and extensor units is the net torque on the elbow joint. Torque generators can be considered as a rotational form of Hill's muscle model (Fig. 2).

In this rotational form, muscle fibre length, tendon length and musculotendon length is represented by muscle angle (θ_m), tendon angle (θ_e) and joint angle (θ_j), respectively. The relation between these variables are expressed in Eq. (2) (Fig. 2b). The joint angle is the relative angle between the upper arm and the forearm at any instant.

$$\theta_m + \theta_e = \theta_j \qquad (2)$$

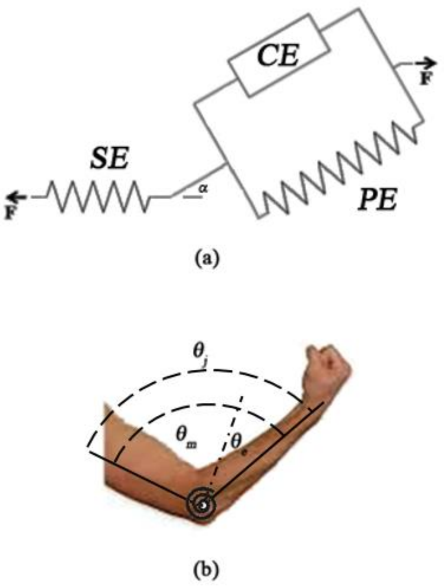

Figure 2. (a) Hill-type muscle model; (b) torque generator

The contractile element *(CE)* of the muscle model determines the relation between the torque, the muscle angle and the muscle angular velocity (contraction velocity). This torque value (T_{con}) is the maximum voluntary torque and has to be multiplied with the muscle activation, *a(t)*. In addition, differential activation, $d(\dot{\theta}_m)$, may be used as a correction considering the depression in muscle extension (Eq. 3). The torque can also be calculated through the series elastic element *(SE)* using the torsional spring constant, k_t, which represents the tendon stiffness.

$$T_{con}(\theta_m,\dot{\theta}_m)*a(t)*d(\dot{\theta}_m) = T = k_t\ \theta_e \qquad (3)$$

The muscle activation is a function of time and ranging from 0 (no activation) to 1 (full activation). Muscle activation profiles describe how the activation changes during the period of simulation. Parametric curves are used for muscle activation profiles and the parameters are determined via an optimisation process to match the simulation result with the actual motion. A sample activation profile is presented in Fig. 3.

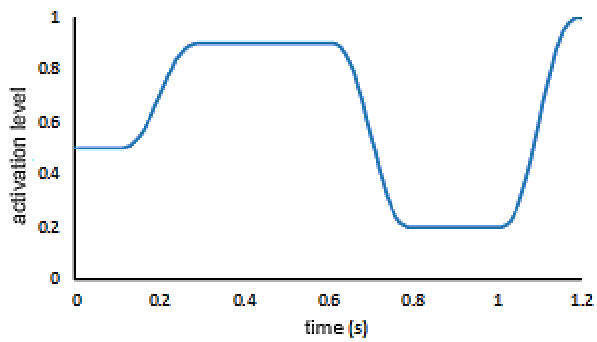

Figure 3. A sample activation profile generated with 9 parameters

The simulation model can be separated into two parts as the dynamics of the body segments and the muscular mechanics part. Eq. (1) describes the dynamics of the body segments whereas Eq. (2) and (3) describe the muscular mechanics part. The torque and joint angle terms appear in both parts and relate the two parts. The estimated torque values are input to the body segments part and the output is the motion of the forearm i.e. change in the muscular geometry. On the other hand, muscular geometry is used to determine the amount of torque generated at the elbow.

Eq. (1) and (2) are two differential equations and can be solved by applying numerical methods. In this study, 4th order Runge-Kutta method is used to solve the differential equations in both muscular part and the dynamics of the body segments. Two different techniques are used for the solution of the equations.

In the first technique, two parts solved separately at each integration step. The output from the solution of one part in a step is used as an input to the other part. This can be summarized in Fig. 4. The same procedure continues at each integration step until the end of the simulation

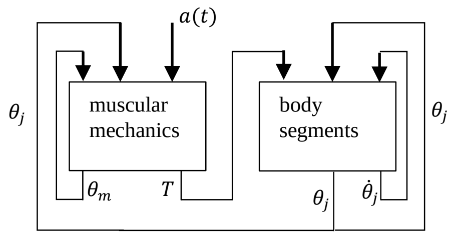

Figure 4. A schematic representation of the first solution technique

In the second technique, all equations are considered simultaneously at each integration step. Therefore, there is no distinct parts in the model. A combinatory Runge-Kutta method is applied to both differential equations.

Currently, the model is developed and two solutions method are being applied. Numerical results will be presented once the results from the both methods are obtained.

Conclusions

Two different solution techniques of the equations that govern the human motion will be compared and discussed. The first technique uses separate solutions of each part of the model at each integration step. This brings modularity to the model and therefore, the solutions can be obtained with relatively less computational effort. However, the values of the variables in one part appears to be unchanged with respect to other at each integration step and the change of the variables in one part can affect the other part only in the next step.

The second technique uses all equations simultaneously at each integration step. Since a combinatory Runge-Kutta is applied, the computational effort is higher than the first technique. The results are expected to be more accurate. The changing of all variables taken into account at the same time that result in less error during the numerical solution. After having the comparison of both methods a particular solution technique can be proposed to all current and forthcoming studies.

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