BoB – biomechanics in MATLAB

James Shippen[1], Barbara May[2]

[1, 2] Coventry University, United Kingdom

E-mails: [1] *j.shippen@coventry.ac.uk (corresponding author)*, [2] *barbara.may@coventry.ac.uk*

Abstract. Biomechanics is a maturing discipline with numeric analysis of kinematic and kinetic data becoming widespread within academic research institutions and commercial organisations. Many engineers and scientists engaged in biomechanical analysis already routinely use MATLAB as it provides an environment that is productive for a broad range of analysis, facilitates rapid code development and provides sophisticated graphical output. Therefore, a biomechanical package which is based within the MATLAB environment will be familiar to many analysts and will inherit much of the analysis capabilities of MATLAB. This paper describes BoB (Biomechanics of Bodies) which is a biomechanical analysis package written in MATLAB M-code, capable of performing inverse dynamics analysis, using optimization methods to solve for muscle force distribution and produces sophisticated graphical image and video output.

Keywords: inverse dynamics, muscle force distribution, MATLAB.

Introduction

With the increased power and capabilities of technical computing, simulations of human movement have been able to provide the opportunity to learn how components interact to produce coordinated movement [1]. Several software programmes have been designed to simulate human movement but each system has defined the parameters of the musculoskeletal system differently. The number of muscles which have been included in the individual programmes, the ease of use and outputs in terms of graphics and muscle forces vary considerably.

For example, "OpenSim" which was developed at Stanford National Institute of Health Centre for Biomedical Computation is an open source software system which allows users to build models of musculoskeletal structures, create dynamic simulations of movement and determine the forces that muscles and bones exert during movement [2]. Another package "LifeMOD" could be scaled to the measurements of the test subject and included 19 body segments, 18 joints but only 38 muscles of the body [3]. "The AnyBody Technology" [4] software was developed for biomechanics and computer-aided ergonomics and marketed for use in product design in the automotive, medical and aerospace industries. It was also used in sports to maximise performance and to enable exercises to be devised targeted at strengthening precise points on the body.

However, many engineers and scientists engaged in biomechanical analysis routinely operate within MATLAB which provides an environment that accommodates a broad range of analysis, facilitates rapid code development and provides sophisticated graphical output. The Biomechanics of Bodies (BoB) biomechanical software is based within the MATLAB environment and inherits much of the analysis capabilities of MATLAB. BoB is written in MATLAB M-code, is capable of performing inverse dynamics analysis, uses optimization methods to solve for muscle force distribution, can run user developed m-code packages and produces sophisticated graphical image and video output.

Methods

BoB is capable of undertaking an inverse dynamics analysis of a subject's movement to calculate the torques occurring at the joints followed by an optimization approach to distribute the loads in the corresponding muscles which traverse the joints. The body of the subject is assumed

to be composed of a number of rigid segments, each with associated mass and rotational inertia properties. These segments are interconnected by joints. Forces act between these segments due to muscles which cross one or more joints. Additionally, external forces, for example ground reaction forces, act on the subject. BoB also contains a muscle model comprising approximately 600 muscle units including the major locomotor muscles of the body.

Inverse dynamics is used to calculate the torques at the joints corresponding to the observed motion and external forces from which the muscles loads are calculated. However, there is not a unique solution as the number of muscles is greatly in excess of the number of joints and hence the number of torques. Therefore, it is necessary to select the one solution for the infinite possible solution which minimises a cost function. Numerous cost functions have been proposed [5]; by default, BoB uses the sum of the square of the muscle activations for the cost function where muscle activation is defined as the muscle force divided by the muscle maximal isometric load. This function has the effect of reducing the maximum muscle activation which will reduce the propensity to fatigue and hence the function can be physiologically justified; however arbitrary user defined cost functions can also be implemented. The optimised solution must also satisfy a set of equality conditions (the external torques due to external forces and segmental inertial forces must equal the torque due to the surrounding muscles at each joint) and inequality conditions (the load in each muscle must be positive as the muscle cannot push and the load must be less than the maximum force the muscle can generate). The minimization of the cost function, subject to equality and inequality constraints, is solved using the interior-point-convex algorithm implemented in the MATLAB QUADPROG [6] function. The interior-point-convex algorithm attempts to follow a path that is strictly inside the constraints. It uses a presolve module to remove redundancies, and to simplify the problem by solving for components that are straightforward. If the cost function is a higher order than quadratic the Interior Point algorithm is implemented in the FMINCON [7] function.

To undertake the inverse dynamics analysis, the time history of the joint articulations, and their time derivatives, must be available. BoB can accept joint angles as closed form equations which are a function of time however this is typically limited to idealized situations such as teaching examples. More realistic joint angle time histories are obtained from motion capture systems – BoB has an interface to read motion capture data directly from C3D files as produced by optical tracking systems Vicon, Qualisys and CodaMotion systems and MVNX files from the Xsens magneto-inertial system. As an example of an application of the BoB biomechanical analysis software, the loads in the lumbar region of the back were calculated for 7 amateur and 4 professional horticulturalists during hedge trimming. The movements of the subjects were measured using a 12 camera Vicon optical tracking system. The ground reaction forces were measured using 2 AMTI OR6-7 forceplates.

Results

Following the measurement of the subjects' movements and external forces, BoB was used to calculate the torques occurring at each of the major joints and the muscle force distribution as described above. Figure 1 shows an example of the muscle loading distribution. The joint contact loads were calculated by the vector summation of the forces of constraint at the joints and the forces in the muscles traversing the joint. Figure 2 shows typical joint contact forces occurring between the sacrum and L5 vertebra for amateur and professional horticulturalists.
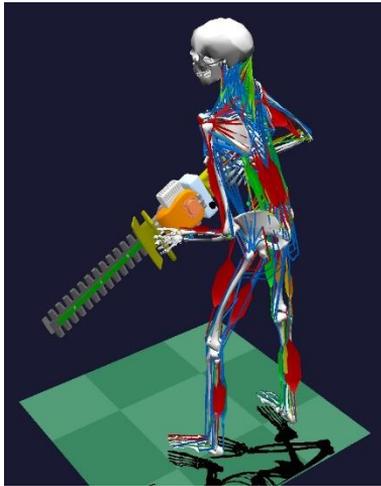
Fig. 1. Muscle activations are indicated by the shading and bulging
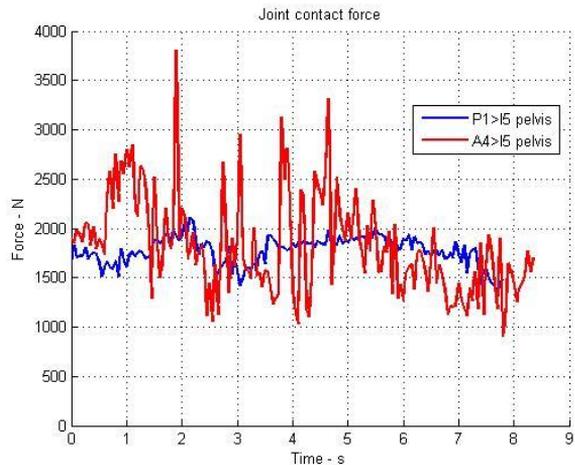
Fig. 2. Typical joint contact forces between the sacrum and L5 vertebra for professional (blue) and amateur (red) horticulturalists

Conclusions

A biomechanical analysis package called BoB (Biomechanics of Bodies) has been written in m-code within the MATLAB environment. BoB inherits much of the analysis capability of MATLAB and will be familiar to existing MATLAB users resulting in a minimal learning curve and rapid productivity. BoB can calculate joint torques, muscle load distribution and joint contact forces. BoB can acquire motion capture data from any system which produce files in the industry standard format C3D or MVNX formats. BoB can be used as an analysis tool in a variety of disciplines i.e. sports, ergonomics, product development and health sciences. In this example BoB was used to analyse the action of horticulturalists and it was found that professional horticulturalists adopted a posture and action which resulted in significantly lower joint contact forces between the sacrum and L5 vertebra than observed in the amateurs.

BoB can be downloaded from http://www.marlbrook.com/download.

References

[1] Pandy, M. 2001. Computer modeling and simulation of human movement, *Annual Review of Biomedical Engineering* 3: 245–273. http://dx.doi.org/10.1146/annurev.bioeng.3.1.245
[2] *OpenSim* [online]. 2010. Stanford University [cited 22 February 2016]. Available from Internet: http://opensim.stanford.edu/
[3] *LifeMOD* [online]. 2016. LifeModeler, Inc. [cited 22 February 2016]. Available from Internet: http://www.lifemodeler.com/
[4] *AnyBody Technology* [online]. 2016. Aalborg University [cited 22 February 2016]. Available from Internet: http://www.anybodytech.com/
[5] An, K. N., *et al.* 1984. Determination of muscle and joint forces: a new technique to solve the indeterminate problem, *Journal of Biomechanical Engineering* 106(4): 364–367. http://dx.doi.org/10.1115/1.3138507
[6] Coleman, T. F.; Li, Y. 1996. A reflective Newton method for minimizing a quadratic function Subject to bounds on some of the variables, *SIAM Journal on Optimization* 6(4): 1040–1058. http://dx.doi.org/10.1137/S1052623494240456
[7] Byrd, R. H.; Gilbert, J. C.; Nocedal, J. 2000. A trust region method based on interior point techniques for nonlinear programming, *Mathematical Programming* 89(1): 149–185. http://dx.doi.org/10.1007/PL00011391