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Farahani, Saeed Davoudabadi; de Zee, Mark; Andersen, Michael Skipper; Lund, Morten Enemark; Rasmussen, John

Publication date:
2011

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Farahani, S. D., de Zee, M., Andersen, M. S., Lund, M. E., & Rasmussen, J. (2011). *Prediction of the Movement Patterns for Human Squat Jumping using the Inverse-Inverse Dynamics Technique*. Abstract from XIII International Symposium on Computer Simulation in Biomechanics , Leuven, Belgium. http://www.anybodytech.com/fileadmin/downloads/ComputerSimulationISB2011_AnyBody_Prediction_squat_01.pdf

XIII International Symposium on Computer Simulation in Biomechanics
June 30th - July 2nd 2011, Leuven, Belgium

PREDICTION OF THE MOVEMENT PATTERNS FOR HUMAN SQUAT JUMPING USING THE INVERSE-INVERSE DYNAMICS TECHNIQUE

Saeed Davoudabadi Farahani[1], Mark de Zee[1,2], Michael Skipper Andersen[1], Morten Enemark Lund[1] and John Rasmussen[1]

[1] *M-tech, Aalborg University, 9220 Aalborg East, Denmark.*
[2] *Department of Health Science and Technology, Aalborg University, Denmark.*
Email: sdf@ m-tech.aau.dk

INTRODUCTION

Several efforts have been made to simulate human vertical jumping to gain insight into the coordination and adaptation in human segmental movement. It has been reported that different subjects show a stereotyped kinematics in squat jumping and, except the small differences in the initial body configuration, the segmental angle histories converge to a common kinematic pattern [1]. The control strategy used in vertical jumping has been investigated by Bobbert et al. [2], and the effect of arm swing in the vertical jump performance was investigated by Lees et al. [3]. It was demonstrated that the arms build up the energy in the early pushing-off phase and transfer it to the rest of the body shortly before takeoff.

We studied the prediction of the movement pattern of human vertical jumping using a new optimization-based technique called Inverse-Inverse dynamics. This method is implemented into the AnyBody Modeling System (AMS) [4] and it is a computationally efficient method for human posture and movement prediction based on three-dimensional musculoskeletal models.

Inverse-Inverse dynamics is capable of predicting human movements provided that a proper objective function can be found. One of the big issues in human movement prediction is how the Central Nervous System (CNS) controls the human movement and which objectives lie behind its choices? In some phenomena, such as maximum height jumping, the objective function is clear but in many cases it is less obvious. In maximal vertical jumping the objective is to maximize the elevation of the center of mass of the whole body. However, for sub-maximal jumping, some researchers have reported that energy expenditure is taken into account [5]. Other possible criteria for sub-maximal jump movement pattern prediction could be minimization of muscle stress, minimizing jerk or muscle activation, but nothing has been reported on these issues yet.

Method

In this study, Inverse-Inverse dynamics was used to predict the movement patterns in human vertical jumping. Inverse-inverse dynamic can, just as optimal control strategies, be subjected to optimization to determine the optimum motion. The novelty of the method lies in the choice of independent variables. While optimum control strategies traditionally use muscle activation or joint moment variations, inverse-inverse dynamics parameterizes the movement and treats joint moments or muscle activation as dependent variables. This means that if the motion is partially unknown, some parametric functions can be assumed and the optimization algorithm based on the results of the inverse simulation identifies the unknown parameters. In other words, the joint angles of the musculoskeletal model are found using optimization and the forces or moments needed for motion are calculated using inverse dynamics (Fig. 1).

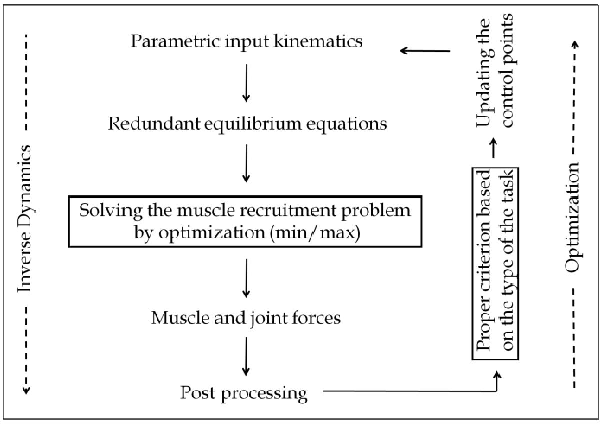

Fig 1: Inverse-Inverse dynamic method to predict human movement.

The independent parameters of the optimization problem were the joint angles of hip, knee and ankle described by means of fourth order B-splines. The muscular load sharing problem (redundancy) is solved by minimizing a cost function. In this study a min/max formulation was used subject to some physiological constraints [4].

Maximizing the height of body center of mass (h) is equal to maximize the vertical takeoff velocity. By neglecting air resistance, and according to the law of conversation of mechanical energy for the flight phase of the jump, the airborne phase can be treated as a projectile in free flight. The relationship between maximum jump height, *h*, and takeoff velocity v_1 of the center of mass is given by:

$$h = \frac{{v_1}^2}{2g} \qquad (1)$$

Where *g* is the gravity acceleration. To maximize *h*, v_1 should be maximized before takeoff. Applying the impulse-momentum theorem gives the changes in the body momentum:

$$\int_{t_0}^{t_1}(F_{GRF} - mg)dt = m(v_1 - v_0) \qquad (2)$$

The model starts jumping from a stationary position (t_0) so the v_0 (initial velocity) is zero. Substituting v_1 from (2) into (1) results in:

$$h = \frac{1}{2m^2 g}\left(\int_{t_0}^{t_1}(F_{GRF} - mg)dt\right)^2 \qquad (3)$$

A constrained optimization was used to optimize the cost function (eq. 3) while no muscle at any time can be loaded above its maximum strength.

RESULTS AND DISCUSSION

It can be seen that the model can predict a taking off configuration in which the joints are almost fully extended. The jump height is 8 cm by using the initial value for design variables. After optimization conduction, the jump height was increased to 19 cm.

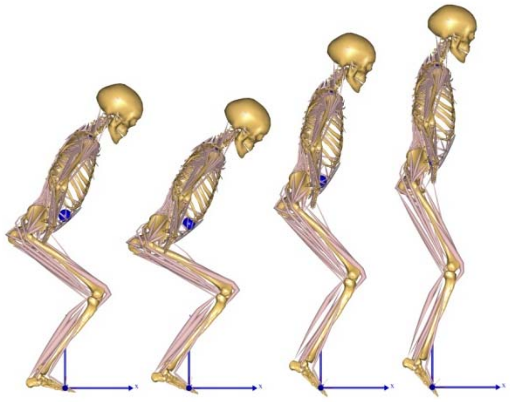

Fig 2: AnyBody squat jump model with 75 kg weight and 180 cm height.

The optimized movement pattern of jumping can be seen in figure 3. The optimization results show a proximodistal sequence of segmental rotation which is in agreement with experimental observations [1].

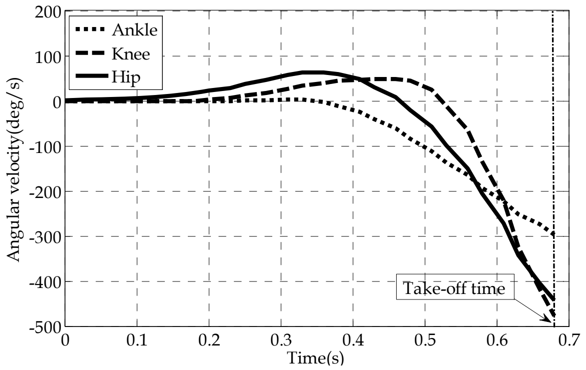

Fig 3: Joint angular velocity after optimization

Figure 4 shows the variations of ground reaction force during the ground contact phase. The early negative slope of force curve shows a counter movement which was identified by the optimization algorithm as advantageous to reach the maximum jump height.

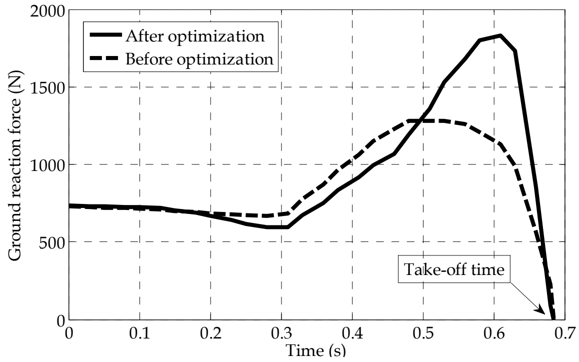

Fig 4: Ground reaction force

CONCLUSIONS

The results indicate that inverse-inverse dynamics is capable of predicting realistic motion patterns by means of optimization. The method can potentially lead to more efficient motion prediction because it is typically easier to parameterize a few degrees of freedom than the activation of a large number of muscles. Hence, this method leads to a relatively small number of design variables. Future work includes cases in which the objective function is not as straight forward as in high jumping.

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