OPTIMAL DYNAMICS OF HUMAN VERTICAL JUMPING

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INTRODUCTION

The human central nervous system (CNS) continuously coordinates body motions despite the presence of kinematic and kinetic redundancy. The early observations of human movements suggested that the CNS coordinates the motion by minimizing a physiological cost function. In this research, we are taking advantage of this speculation to study and predict the dynamics of a vertical jump. The objectives of this research are: first, to develop a simple yet computationally efficient biomechanical model of a human, and second, to predict the body dynamics during jump using optimal control theory.

METHODS

In this research, a two-dimensional model of the human body in the sagittal plane actuated with three joint torques is developed as shown in Figure 1. This model consists of foot (FT), shank (SH), thigh (TH) and upper-body segments, which are connected to each other via ankle, knee and hip joints, respectively. The upper body is comprised of a rigidly connected head, arms and trunk (HAT). In this research, the arms are assumed to be fixed to simplify the optimal control problem. This model is used to simulate the optimal dynamics of the body during squat, take-off and flight phases of a jump.

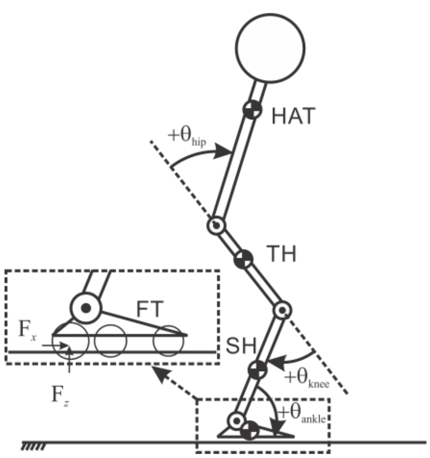

Figure 1: Schematic of the torque-actuated human model

Unlike an inverse dynamic analysis where the foot-ground contact forces are measured and fed into the simulation, in this predictive forward dynamic simulation these contact forces are unknown, and have to be calculated during the simulation. Therefore, an accurate contact model has to be implemented. In this research, a nonlinear volumetric contact model as described in [1] has been incorporated to the foot. Here, it is assumed that the foot is in contact with ground at the heel, 1st metatarsal joint and toe; three spheres are used to represent each contact. By providing larger contact surfaces in comparison with simple spring-damper contact models, the spheres can improve the fidelity of the foot-ground contact.

A variable-order orthogonal collocation dynamic optimization method (GPOPS-II, RP Optimization Research, USA) [2] has been used to optimize the simulation of a fully predictive vertical jump. An interior-point optimizer (IPOPT, Biegler et al., USA) has been used to find the optimal solution of the resulting nonlinear problem.

RESULTS

Figure 2 shows the snapshots of the optimal vertical jump predicted by maximizing the head height while minimizing the joint torques.

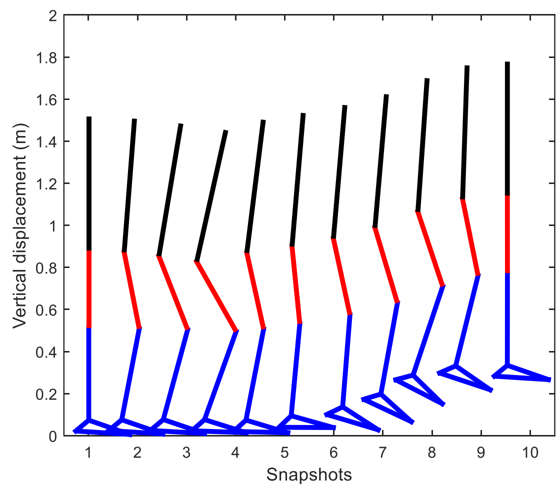

Figure 2: Snapshots of predicted vertical jump

DISCUSSION AND CONCLUSIONS

In this research, an optimal dynamic platform has been developed to simulate the dynamics of human motions such as jumping and gait. This framework has been used to predict the optimal dynamics of all three phases of jump. As a future work, the arms will be added to study the effect of arm swing on the jump height, and the simulation results will be compared to experiments.

REFERENCES

[1] Shourijeh, M. S., & McPhee, J. (2015). Foot–ground contact modeling within human gait simulations: from Kelvin–Voigt to hyper-volumetric models. Multibody System Dynamics, 35(4), 393-407.

[2] Patterson, M. A., & Rao, A. V. (2014). GPOPS-II: A MATLAB software for solving multiple-phase optimal control problems using hp-adaptive Gaussian quadrature collocation methods and sparse nonlinear programming. ACM Transactions on Mathematical Software (TOMS), 41(1), 1.

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