

Elastic Collision in Dynamic Walking of Bipedal Locomotion

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SUMMARY

Collision phase has significant effects on energetics of bipedal walking which includes two impact of heel strike and toe touch down. This work is aimed to analytically study the energetics of the bipedal walking with elastic collision phase. A simplified model of bipedal walking is used in this work including a foot, a leg (knee is locked) with lumped masses (foot and body) and an elastic ankle joint (with adjustable stiffness). Results of analytical study and computer simulations illustrate an improvement in energetics of bipedal walking caused by elastic collision with adjustable stiffness.

INTRODUCTION

Stiff joints make legged locomotion unnatural and inefficient, since the natural dynamics would not be obtained during locomotion. Among all the complexity involved in legged locomotion, elasticity at the ankle joint is the focus of this study in which it is believed to be one of the most important factors of efficient bipedal walking [1-3]. The elasticity not only reduces the impact at each foot strike but also creates a semi-passive locomotion. Part of the energy of the biped can be stored in the elastic form during the collision phase and be returned to the biped during the rebound phase. This natural behavior of energy interaction is in the context of Dynamic Walking.

METHODS

A simplified model of bipedal walking is proposed in this study including a foot, a leg and an adjustable stiffness ankle joint. The trailing leg during the double support phase is modeled by a linear spring. The spring model assists in simulating the energy injection to the biped through the trailing leg during the double support phase. Dynamical model of the biped is analyzed to study the effects of elastic collision phase on energetics of walking. Then, a controller is designed based on the dynamics model of the biped to adjust the stiffness of the ankle joint in different walking velocities to minimize the energy loss during the collision phase. Computer simulations are performed to develop a step-to-step velocity regulator based on geometric progression to stabilize the biped in consecutive walking steps.

RESULTS AND DISCUSSION

The analytical study of the model showed that the energy loss at the heel strike is negligible (because of kinematics

configuration) and the main impact is at the toe touch down. In addition, kinetic energy loss at the toe touch down has direct relation to the square of the foot angular velocity. In order to minimize the energy loss at the toe touch down, the angular velocity of the foot must be minimized before the impact. In fact, this minimization can be done by applying negative work through actuating a negative torque at the ankle joint which causes another sort of energy loss. However dynamically charging an elastic tendon would be a better option, since the stored energy can be used later during the rebound phase. In this work the elastic tendon is located parallel to the ankle joint. Our study showed that the process of charging the elastic tendon at the ankle joint, with proper stiffness, causes a change in direction of the velocity of the body from downward to upward during the collision phase. This has been observed in human walking locomotion by other researchers. The amount of energy that should be stored in the elastic tendon, in order to obtain the energy loss minimization at the toe touch down, is varied since the bipedal walking gait and velocity can be varied in a wide range. Capability of adjusting the stiffness of the tendon in adapting the energy storage of the biped in such a variation is tested in this work which the results illustrate its necessity in improving the energetics. In addition, a control algorithm is successfully developed to regulate the step-to-step velocity of the biped in order to keep the stability of the biped in multiple walking steps. The controller is based on adjusting the energy input and output of the biped during the double support phase. The simulation results show that the controller is successful in regulating the velocity of the biped at the mid-stance in each step.

REFERENCES

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