Asymmetric Trajectory Generation for the Biped Ascending Stairs

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Abstract

Objectives

Asymmetric gait generation problems of the biped negotiating stairs have been solved with the method of genetic algorithm (GA), and influences of osteoarthritis (OA) on hip joint biomechanics in stair ascent were further investigated in this paper.

Methods

Gait adaption is an important ability for people with hip OA to maintain stable walking when going up and down stairs or climbing sloping surfaces. It is very important to study how OA influences gait stability because persons with hip OA have more risks of falls. Many studies on the biped robots focused on generating the control methods for all kinds of motions closer to human-like movement. In order to generate optimal asymmetric gaits for the biped walking up and down stairs, the main design criteria were defined to ensure minimal energy and gait stability. Gong and Schiehlen [1] and Gong [2] have reported that it is effective to use the motion/force control scheme to achieve stably impactless walking for the biped walking on slopes and stairs. Many studies demonstrated the results about generating the optimal trajectories by using GA as the optimization method for the bipedal walking on uneven terrains [3-5]. Asano and Luo reported that the optimal bipedal gaits could be obtained if the mean value of the inter-leg angles kept constant [6]. An online asymmetric running trajectory gait generation approach was proposed to keep stable bipedal locomotion, based on the criterion of stable running [7]. Gait variability was greatly influenced by walking speed and OA severity [8].

This paper proposes GA as the optimization method to search for the optimal asymmetric trajectories for the biped negotiating stairs while maintaining a low energy control. Simulations were performed based on a 7-linked biped model, by using the multibody formalism Neweul-M^2 [9]. The 7-DOF biped model was used to simulate persons with unilateral hip OA ascending stairs. The optimal asymmetrical trajectories of the biped ascending stairs were generated by GA. Mechanical efficiency is crucial in studying the asymmetrically optimal bipedal gaits. The specific resistance (ε) is minimized to be used as the objective function [10] in this paper, and the definition of ε is:

$$\varepsilon(v) = \frac{P(v)}{mgv}, \tag{1}$$

where P is the mechanical power output and mg is the weight of the biped.

Gait characteristics were changed obviously for the individuals with unilateral hip OA because of increased pains, muscle weakness, ect. It is reported that the motion of the affected hip joint was obvious narrowed because of hip OA. In this study, we considered the step-by-step motion for the biped going up stairs. Ranges of affected hip joint movement were limited because of pains. Speed and stance duration of affected hip joint and non-affected hip joint were calculated with GA for the biped ascending different heights of stairs. Finally, energy consumption was compared for the biped ascending different heights of stairs.

Results and Discussions

The optimal trajectories of lower limb joints and minimal energy consumption were obtained with GA for the biped ascending different stairs. The first results demonstrated that the biped could walk stably with desired velocities. Gait transitions between the affected leg and non-affected leg were obtained for different heights of stairs with GA. The affected hip joint demonstrated slower velocity and greater stance duration during ascending higher stairs.

One of the advantages of GA lies in its efficiency and robustness, which is the reason why GA is frequently used to study optimal trajectories for the bipedal walking. Our results suggest that GA can be used to better understand hip joint biomechanics of persons with hip OA during challenging activities such as going up and down stairs. Further research is necessary to understand the implications of these results on hip OA.

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