Optimal Trajectory Generation for the Biped Walking on Inclined Surfaces

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Abstract

Objectives

This paper presents an optimal trajectory generation method for the biped walking on inclined surfaces by changing some boundary conditions. The minimal energy is used as a criterion to propose a dynamically stable and optimal trajectory generation method for the impactless biped walking.

Methods

A biped robot should be able to navigate artificial environments including stair-cases, sloping surfaces, door thresholds, etc.. Questions which demand our serious consideration with respect to bipedal walking on uneven surfaces are to minimize their energy consumption and to keep them from falling down to the ground. A motion/force control scheme for the biped impactless walking has proven to be used effectively to achieve stable walking on slopes and stairs, see e.g. Gong and Schiehlen [1] and Gong [2, 3]. Lim et al. proposed the method to produce the optimized gaits for the robot and to improve the energy autonomy and stability using the real-coded genetic algorithm (RCGA) as the optimization tool [4]. In the presented approach, genetic algorithm (GA) is used to search for the optimal trajectories when the biped walks on inclined surfaces with different angles (γ) at different velocities (v), based on energy criteria. Various computer simulations were performed based on a 7-linked biped robot model, which was built using the multibody formalism Neweul-M^2 [5].

Four design variables using in this article are step length (s), percentage of duration of single support phase (SSP) in one gait cycle (P_{ssp}), percentage of duration of swing foot lifting into the vertical direction in SSP (P_{swl}), and the height from the current slope surface to the highest position of the sole of swing foot (h_A). The initial population is 10 and the maximum number of generations (GN_{max}) is 500. The crossover ratio is 0.9 and mutation ratio is 0.02. If the number of generations reaches GN_{max} or if the value of the objective function does not change for 10 conservative generations, the simulation is terminated. All the biped locomotion were studied with slow speed ($0.4m/s$), medium speed ($0.6m/s$) and fast speed ($0.8m/s$). The angles of slopes range from -20° to 20°, with positive value or negative value for up-slope and down-slope, respectively.

For legged robots, the specific resistance (ε) is used frequently to analyze and compare the performance [6]. In this research, ε is regarded as the objective function (to be minimized), which is defined as:

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

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

Results

The optimal values for the biped walking on inclines were determined by the minimum specific resistance (ε_{min}). h_A equals to the lower boundary for all locomotion. Figure 1a shows that the minimal energy consumption increases with the increase of absolute value of γ. And ε_{min} increases with increasing walking speed. As demonstrated in Fig. 1b and 1d, walking speed doesn't have great influences on the optimal step length and P_{swl} for different γ. Figure 1c depicts that P_{ssp} are between 70.8% and 80.0% for different γ and v. It means that the single support phase consumes most of the energy, relatively compared to the double support phase. Figure 1d shows that the values of P_{swl} are between 20.0% and 31.0% for downslope walking, which increase with decrease of absolute value of γ. On the contrary, the values of P_{swl} increase with increasing γ for upslope walking, which are from 44.8% to 77.0%.

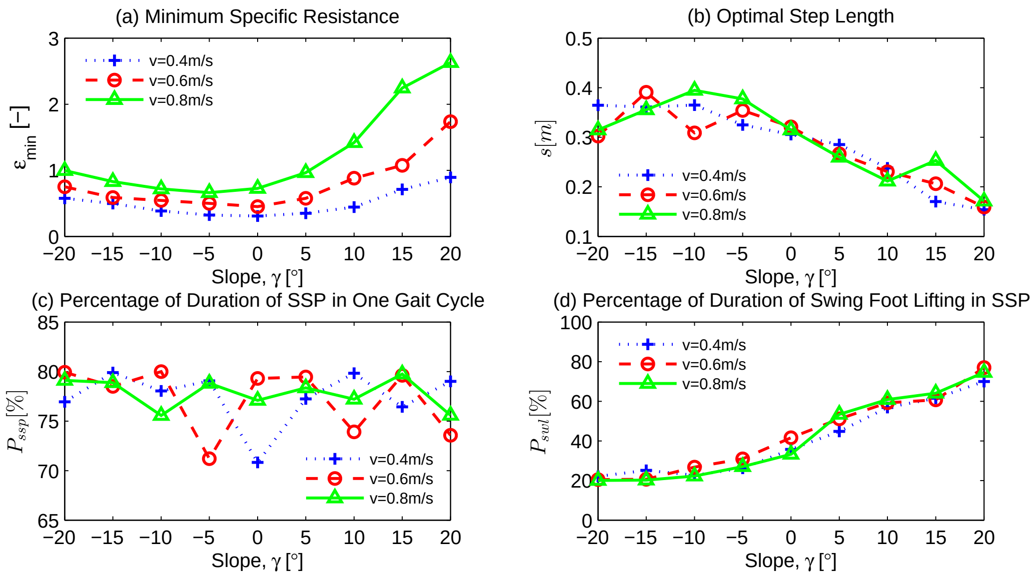

Figure 1: Optimal data for different inclined surfaces: (a) minimum specific resistance (ε_{min}); (b) optimal step length (s); (c) percentage of duration of SSP in one gait cycle (P_{ssp}); (d) percentage of duration of swing foot lifting into the vertical direction in SSP (P_{swl}).

Discussions

Simulation results show that the proposed method is able to generate the optimal trajectories of the biped walking on inclined surfaces. It has been observed that walking with faster speed consumes more energy for each gradient of slope. As a result, it makes it possible to generate various locomotion trajectories of biped robots simply by appropriately changing some of the boundary conditions.

Acknowledgements

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