Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(12) (2021) 837-840
DOI: 10.22060/mej.2019.16121.6282

Simultaneous Optimization of a Convex Sole as a Foot and Hip Trajectory for a Biped Robot with an Ankle without an Additional Degree of Freedom

F. Ghafouri, M. H. Honarvar*, M. M. Jalili

Mechanical Engineering Department, Yazd University, Yazd, Iran

ABSTRACT: Foot geometry greatly affects gait characteristics and it determinants. This research deals with analyzing gait when foot-ground contact occurs on a convex curve namely sole curve. Designing sole curve is also included in this work, targeting least energy consumption during walking on a flat ground. The famous point mass model has been improved to a model with a moving contact point on a convex sole without adding an extra degree of freedom. As the convex sole is added to the model, motion reconstruction is needed because of the effects of the model's geometry on optimized gait cycle. Therefore, in this research, simultaneous optimization has been done to find the optimized sole shape and hip trajectory. To avoid high computational cost, optimization variables have been coded into vectors with limited dimensions and obtained by using particle swarm optimization and steepest descent algorithm together. Kinematic constraints and requirements of a continues, repetitive and symmetrical locomotion have been driven and satisfied during optimization. The results have been shown that optimization of the sole shape and hip trajectory has great effects on the cost function.

Review History:

Received: 14 Apr. 2019
Revised: 28 Jul. 2019
Accepted: 22 Sep. 2019
Available Online: 6 Oct. 2019

Keywords:

Gait cycle
Sole
Energy consumption
Optimization

1- Introduction

Ground contact part of human (foot), humanoid robots and prothesis has been studied widely because of its important role in the specification of the gait cycle in recent years. It helps to have a smooth and stable movement [1-4]. Also, it can control energy loss in heel contact [5-8] and energy consumption during walking [9,10]. According to limited studied on foot geometry, in this study tries to optimize foot shape and hip trajectory together to have a continues, repetitive and symmetrical locomotion with the least energy consumption. To achieve this purpose, two convex soles have been added to end of the legs of a famous pointed mass model as feet. At the start of optimization process, sole shape has been coded to a vector with three dimensions and also hip trajectory are defined with four parameters. Particle Swarm Optimization (PSO) and Steepest Descent (SD) algorithm have been employed simultaneously to find optimized sole shape and hip trajectory with minimum energy consumption and energy loss during heel contact.

2- Methodology

In order to study the human walk, famous pointed mass model has been employed. Leg length changes are provided by an active prismatic actuator and the only mass is located on the hip. This model has been improved by adding convex sole as a foot without adding extra degree of freedom. A schematic of this model has been shown in Fig. 1. The four

$$x_H + r\sin\theta = x_C + q\cos(\theta + \beta_C) \tag{1}$$

$$y_H - r\cos\theta = q\sin(\theta + \beta_C) \tag{2}$$

$$q'\sin(\theta + \beta_C) + q\cos(\theta + \beta_C) = 0 \tag{3}$$

$$x_C = x_{C_0} + \int_{\beta_0}^{\beta_C} \sqrt{(q^2 + q'^2)}\, d\beta \tag{4}$$

kinematic equations can be extracted (Eqs. (1) to (4)).
Due to prevent impact, three constraints have been added to the hip trajectory:

$$y_{H_1} = y_{H_{end}} \tag{5}$$

$$\left(\frac{\partial y_H}{\partial x_H}\right)_1 = \left(\frac{\partial y_H}{\partial x_H}\right)_{end} \tag{6}$$

$$V_1 = V_{end} \tag{7}$$

Also, equations of motion can be obtained using free body diagram and newton's law.

*Corresponding author's email: hadihonavar@yazd.ac.ir

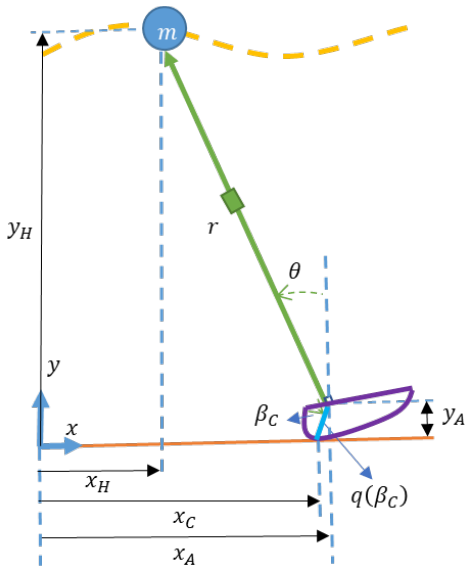

Fig. 1. Comparison of total moment vs. azimuth angle for starting mode

$$F - mgcos\gamma = m\left(-\ddot{x}_H sin\gamma + \ddot{y}_H cos\gamma\right) \tag{8}$$

$$mgsin\gamma = m\left(-\ddot{x}_H cos\gamma - \ddot{y}_H sin\gamma\right) \tag{9}$$

Determining cost function and optimization parameters is the first step in optimization process. In this project, energy consumption is the cost function (Eq. (10)) and sole shape and hip trajectory, which are coded into vectors with three and four dimensions, are the optimization parameters (Eqs. (11) and (12)).

$$W^+ = \int [\frac{F}{mg}.dr]^+ = \int [\overline{F}.dr]^+ \tag{10}$$

$$y_H = Asin^2\left(Bx_H + C\right) + H \tag{11}$$

$$q = Q(1)\beta^6 + Q(2)\beta + Q(3) \tag{12}$$

According to have three constraints on hip trajectory, the cost function can be rewritten as Eq. (13):

$$\min_X W^+ \\ \begin{Bmatrix} G_1 = y_{H_1} - y_{H_{end}} \\ G_2 = \left(\frac{\partial y_H}{\partial x_H}\right)_1 - \left(\frac{\partial y_H}{\partial x_H}\right)_{end} \\ G_3 = V_1 - V_{end} \end{Bmatrix} \tag{13}$$

In this project, optimization process has been contained four steps:

a) PSO algorithm has been used to find optimum values for two parameters A and H in specified ranges.

b) SD algorithm has been used to find an optimum value for parameter B (Till now, optimum trajectory has been extracted for input sole)

c) SD algorithm has been used to find optimum values for parameters Q (1:3).

d) SD algorithm has been used to find optimum values for parameters A and H.

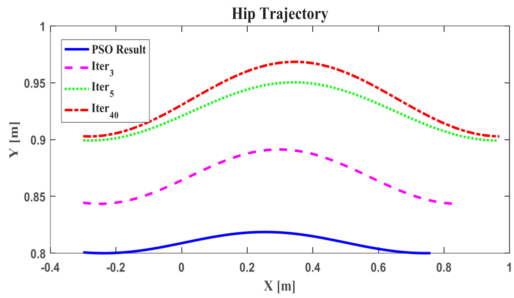

Fig. 2. The flow field and boundary conditions

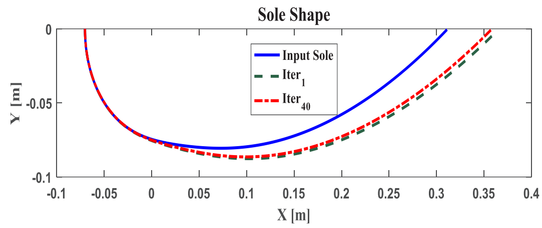

Fig. 3. Verification of straight-bladed turbine total moment coefficient

3- Results and Discussion

PSO and SD algorithm have been used together in four steps to find optimum hip trajectory and sole shape to minimize energy consumption during walking. Optimization process has been repeated in 40 iterations. Finally, optimum hip trajectory and sole shape have been obtained and shown in Figs. 2 and 3:

To show independent of optimization results from initial guess, optimization process has been repeated for five more times and mean and standard deviation of energy consumption have been calculated 0.0202 and 0.000236.

4- Conclusion

In this study, pointed mass model has been used improved by adding convex sole at the end of the leg as a foot without adding extra degree of freedom. After solving kinematic and dynamic equations, PSO and steepest descent algorithm have been employed to optimize sole shape and hip trajectory together to achieve minimum energy consumption during walking. Optimization process has been conducted in four steps and in 40 iterations. Finally, results independence from initial guess has been checked.

Reference

[1] J.R. C. Pongmala, C. Price, R. Baker, Is Foot Contact a Collision, Proceedings of Gait & Clinical Movement Analysis Society 2015 Annual Conference, (2015).

[2] M. Wisse, D.G. Hobbelen, R.J. Rotteveel, S.O. Anderson, G.J. Zeglin, Ankle springs instead of arc-shaped feet for passive dynamic walkers, in: Humanoid Robots, 2006 6th IEEE-RAS International Conference on, IEEE, 2006, pp. 110-116.

[3] S. Sadati, M. Borgheinejad, H. Fooladi, M. Naraghi, A. Ohadi, Optimum Design, Manufacturing and Experiment of a Passive Walking Biped: Effects of Structural Parameters on Efficiency, Stability and Robustness on Uneven Trains, in: Applied Mechanics and Materials, Trans Tech Publ, 2013, pp. 107-111.

[4] P. Mahmoodi, R.S. Ransing, M.I. Friswell, Modelling the effect of 'heel to toe' roll-over contact on the walking dynamics of passive biped robots, Applied Mathematical Modelling, 37(12-13) (2013) 7352-7373.

[5] F. Asano, Z.-W. Luo, The effect of semicircular feet on energy dissipation by heel-strike in dynamic biped locomotion, in: Robotics and Automation, 2007 IEEE International Conference on, IEEE, 2007, pp. 3976-3981.

[6] P.G. Adamczyk, S.H. Collins, A.D. Kuo, The advantages of a rolling foot in human walking, J Exp Biol, 209(Pt 20) (2006) 3953-3963.

[7] J. Li, Y. Tian, X. Huang, H. Chen, Foot shape for passive dynamic kneed biped robot, in: Robotics and Biomimetics (ROBIO), 2010 IEEE International Conference on, IEEE, 2010, pp. 1281-1286.

[8] M.H. F. Ghafouri, M. Jalili, Mechanical and energetic consequences of convex-curved sole in human walking with different patterns, ICROM International Conference (2017).

[9] C. Chevallereau, Y. Aoustin, Optimal reference trajectories for walking and running of a biped robot, Robotica, 19(05) (2001).

[10] G. Capi, S.-i. Kaneko, K. Mitobe, L. Barolli, Y. Nasu, Optimal trajectory generation for a prismatic joint biped robot using genetic algorithms, Robotics and autonomous systems, 38(2) (2002) 119-128.