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Gait Generation for a Small Biped Robot using Approximated Optimization Method

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Abstract. This paper proposes a novel approach for gait pattern generation of a small biped robot to enhance its walking behavior. This is to aim to make the robot gait more natural and more stable in the walking process. In this study, we mention the approximated optimization method which applied the Differential Evolution algorithm (DE) to objective function approximated by Artificial Neural Network (ANN). In addition, we also present a new human-like foot structure with toes for the biped robot in this paper. To evaluate this method achievement, the robot was simulated by multi-body dynamics simulation software, Adams (MSC software, USA). As a result, we confirmed that the biped robot with the proposed foot structure can walk naturally. The approximated optimization method based on DE algorithm and ANN is an effective approach to generate a gait pattern for the locomotion of the biped robot. This method is simpler than the conventional methods using Zero Moment Point (ZMP) criterion.

1. Introduction

Humans have a complicated physical structure and can implement difficult movements. Inspiration from human, during the past several decades, a number of researchers in the world have concentrated on the field of the biped robot (also known as humanoid robot) such as Asimo [1] of Honda, Johnnie [2] of Technical University of Munich, KHR robot series [3] of Kondo Kagaku Co., Qrio [4] of Sony Intelligence Dynamics Laboratory, Inc. The first aim of research carried out in the field of the biped robot attempts to solve the following problem: How can we build a biped robot prototype able to walk as the humans are doing.

To reach this target, there have been some studies to focus on generating gait patterns of the robot based on machine learning methods. For instance, Tang Z. et al. have proposed genetic algorithm based optimization for human walking [5]. Krissana K. and Hasegawa H. have developed the gait generation method based adaptive plan system with genetic algorithm [6]. Kuo P. H. et al. have presented the gait learning by using particle swarm optimization for humanoid robot [7]. Lee B. H. et al. have proposed optimal trajectory generation for a humanoid robot based on fuzzy and genetic algorithm [8]. Such the goal requires a biped robot that is considerably similar to humans in term of its mechanism and motion pattern. However, it cannot be said with certainty that the biped robots developed in recent studies realize a human-like walk. Therefore, the study on robot walking is still continuing.

In this study, to get flexible and natural gait pattern for a small biped robot when it walks on flat ground, we propose a novel approach for gait generation problem based on approximated optimization method. We confirmed the success of this approach through the dynamic simulation of the robot walking process by Adam software.

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2. Simulation model

2.1. Proposed model

In this paper, the KHR-3HV robot of Kondo Kagaku Company was used to build an experiment model. Figure 1 shows the picture of the real robot and the simulation model.

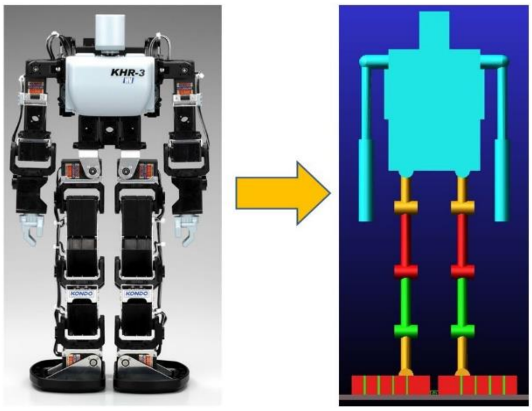


Figure 1. Real robot and simulation model

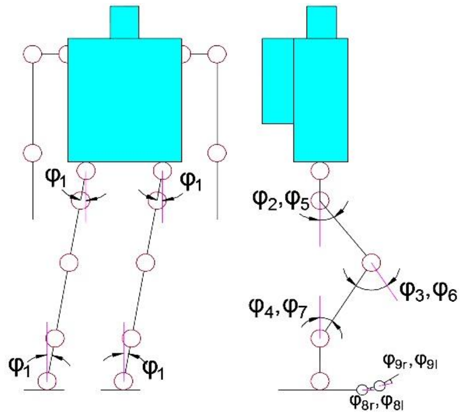


Figure 2. Robot linkage model

A new foot structure composes of heel and many toes is proposed in this study. Each foot has 10 degree of freedom as described in Figure 2. As proven in [9], the biped robot whose big toe width ratio per foot equals 0.28, has the longest walking distance when big toe length is fixed and this ratio is similar to the ratio of human's foot. Thus, the width of big toes and foot were designed of 22mm and 78mm, respectively. The other smaller toes have the same width of 12mm.

In [10], Chockalingam et al. have proved that an average ratio between the foot length and heel varies from 1.196 to 1.426. Thus, in this paper, the length of heel and foot are 95mm and 123mm, respectively. To reduce energy consumption, toe joints were applied by torsion spring that based on principles of torsion and twisting. Spring stiffness coefficient is respectively set of 0.26N.mm/deg, 0.52N.mm/deg to lesser toe joint and big toe joint.

2.2. Motion pattern

Basing on the human walking pattern as depicted in [11], we assumed the robot control data was generated by the gait function as trigonometric function shown in Equation (1). By changing a, b, c, d coefficients, the gait functions will be created to allocate to each joint of the biped robot.

$$\varphi_i(t) = a_i + b_i\cos(\omega t) + c_i\sin(\omega t) + d_i\cos(2\omega t) \quad (1)$$

Where a, b, c, d are coefficients, t is time, ω is angular velocity and i is index of joint.

3. Optimization procedure

3.1. Gait generation

In this study, one cycle was set up to 1.2 seconds. Therefore, angular velocity was calculated as described in Equation (2). We simulated the biped robot in 3 cycles which spent on 3.6 seconds and 1.2 seconds was used for checking robot stability. In simulation, one step took 0.02 second, so the total number of step were 240.

$$\omega = \frac{2\Pi}{1.2} = 5.236 \text{ (rad/s)} \quad (2)$$

Gait functions are assigned to each joint as known in Equation (3-9).

$$\varphi_1 = \begin{cases} 0, & t = 0 \text{ or } t \geq 3.6 \\ \pm 1.5, & t = 0.3 \text{ and } t = 3.3 \\ \varphi_1(t), & 0.3 < t < 3.3 \end{cases} \quad (3)$$

$$\varphi_5 = \begin{cases} 0, & t = 0 \text{ or } t \geq 3.3 \\ 15, & t = 0.3 \\ \varphi_2(t), & 0.3 < t < 3.3 \end{cases} \quad (7)$$

$$\varphi_2 = \begin{cases} 0, & t \leq 0.3 \text{ or } t \geq 3.6 \\ \varphi_2(t + 0.6), & 0.3 < t < 3.3 \\ 15, & t = 3.3 \end{cases} \quad (4)$$

$$\varphi_6 = \begin{cases} 0, & t = 0 \text{ or } t \geq 3.3 \\ 30, & t = 0.3 \\ \varphi_3(t), & 0.3 < t < 3.3 \end{cases} \quad (8)$$

$$\varphi_3 = \begin{cases} 0, & t \leq 0.3 \text{ or } t \geq 3.6 \\ \varphi_3(t + 0.6), & 0.3 < t < 3.3 \\ 30, & t = 3.3 \end{cases} \quad (5)$$

$$\varphi_7 = \begin{cases} 0, & t = 0 \text{ or } t \geq 3.3 \\ 15, & t = 0.3 \\ \varphi_4(t), & 0.3 < t < 3.3 \end{cases} \quad (9)$$

$$\varphi_4 = \begin{cases} 0, & t \leq 0.3 \text{ or } t \geq 3.6 \\ \varphi_4(t + 0.6), & 0.3 < t < 3.3 \\ 15, & t = 3.3 \end{cases} \quad (6)$$

3.2. Problem formulation

The concept of the optimization process is shown as in Figure 3. This figure describes the parameters of the optimization process. Where Z_f and X_f denote the distances of the biped robot from initial position to final position along z-axis and x-axis. R_f is angle of rotation. Design variable vector, objective function, constraint functions and penalty function are defined as described in Equation (10-16).

Design variables (DVs):

$$x = [a_1, b_1, c_1, d_1, a_2, b_2, c_2, d_2, a_3, b_3, c_3, d_3, a_4, b_4, c_4, d_4] \quad (10)$$

Constraint functions:

$$g_1(x) = 20 - |X_f| \geq 0 \quad (11)$$

$$g_3(x) = 243 - Y_f \leq 0 \quad (13)$$

$$g_2(x) = 5 - |R_f| \geq 0 \quad (12)$$

$$h(x) = N - 240 = 0 \quad (14)$$

Penalty function:

$$P(x) = \sum_{i=1}^{3} max(g_x(x), 0) + h(x) \quad (15)$$

Modified objective function:

$$F(x) = -Z_f + \gamma.P \rightarrow \min \quad (16)$$

The objective function is minimized. Where a_i, b_i, c_i, d_i (i= 1,2,3,4) variables are coefficients of gait function. There are four constraint functions. In Equation (11-12), X_f distance and R_f angle are constrained under ±20mm and ±5^o to ensure that the biped robot can walk straight. In Equation 13, Y_f which is the distance from Center of Mass (CoM) to the ground, must be more than 243mm to ensure the robot not to slip and fall down at the final framework. In Equation 14, N is a total simulation step which is equal 240 to check the success of the simulation. In Equation (16), γ is the penalty coefficient set to 1000. Equation (11-14) will be also checked again when the simulation finishes.

3.3. Optimization solution

The optimization process was implemented by the steps as shown in Figure 4.

4. Simulation result

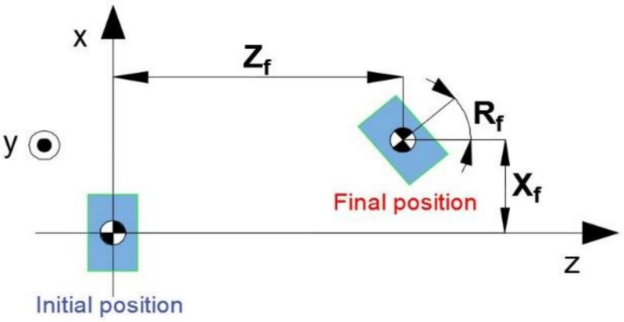


Figure 3. Overview of optimization

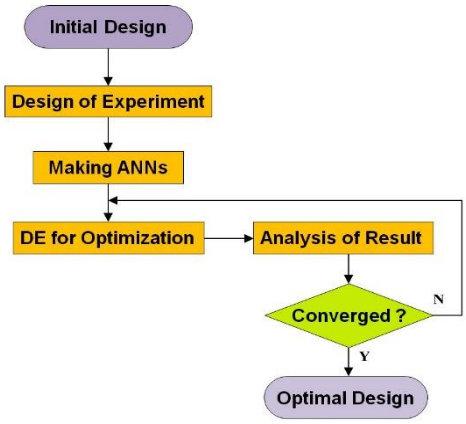


Figure 4. Approximated optimization process

The optimal result is shown as in Figure 5 with X_f, Z_f, R_f of 0.044mm, 177.96mm and 1.203^o, respectively. The trajectory of the robot's CoM is depicted as in Figure 6. As a result, the trajectory of the CoM is close to a waveform of a circular function which is similar to the trajectory of the human's CoM.

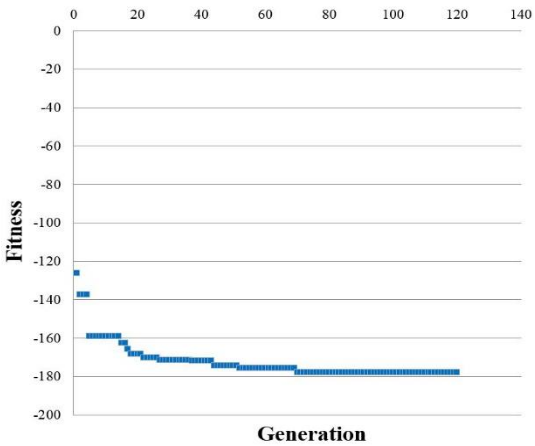


Figure 5. Optimization process convergence

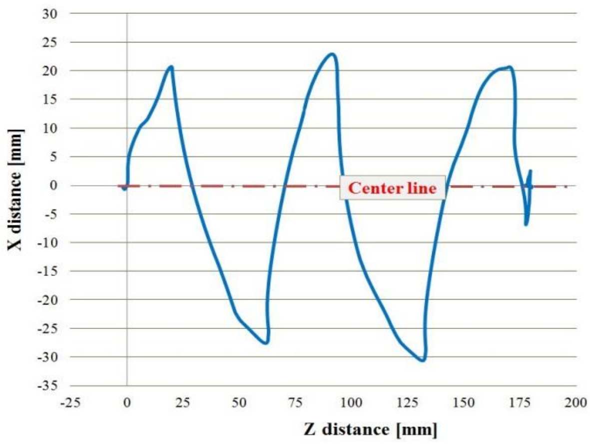


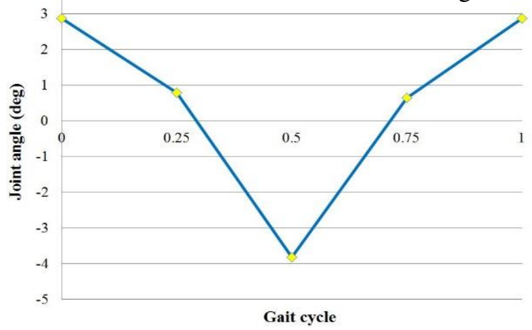
Figure 6. Robot's CoM trajectory

The waveform of the gait function allocated to all joints of the biped robot are shown in Figure 7. We can see that the waveforms of hip and knee joint gait functions are comparable to that of human.

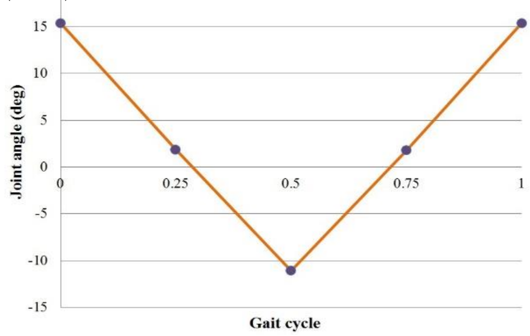
5. Conclusion

In this paper, to enhance walking gait of a small biped robot in the locomotion on flat ground, a novel gait pattern generation method is proposed. The gait pattern is generated by the approximated optimization method based on DE algorithm and ANN. We verified the effectiveness of this approach by dynamic simulation on Adams software. Moreover, the new gait pattern generation method reduced the complexity of the gait pattern generation problem for the biped robot in comparison to the conventional methods using ZMP criterion.

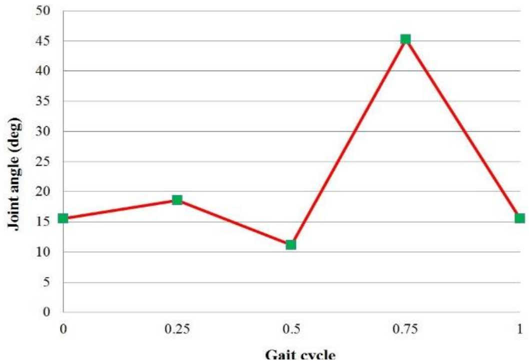
Finally, this study plans to do improvements with the optimization for ankle joint position and length of robot toe.



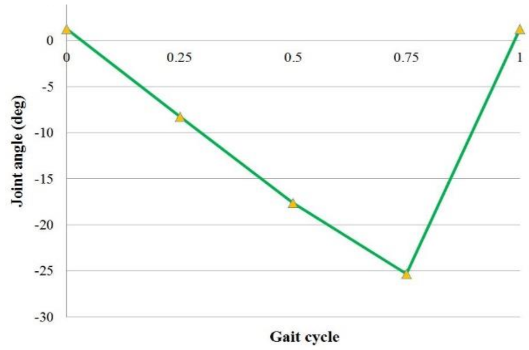
(a) A cycle of gait function (hip and ankle roll joint angle)



(b) A cycle of gait function (hip pitch joint angle)



(c) A cycle of gait function (knee pitch joint angle)



(d) A cycle of gait function (ankle pitch joint angle)

Figure 7. Waveform of the gait functions

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