PROPOSAL OF FOOT STRUCTURE WITH LINEAR SPRINGS FOR BIPED ROBOT

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ABSTRACT

A new foot structure with linear springs is proposed for a 10 degree of freedom (DOF) biped robot in this paper. During the walk, ground reaction force (GRF) begins to appear at the first step of biped robot. That is an important contributor to the instability of biped robot. In this paper, we proposed a new foot structure with two linear springs added to each foot of biped robot. As a result, ankle joints are passive ones. We confirmed the walking behaviour under a motion simulation. The gait parameters are based on human's gait pattern analysis. After the simulated biped robot walks several steps, the obtained result verifies walking functionality of biped robot with a new foot structure.

Keywords: Biped robot; center of mass; multi-body dynamic; degree of freedom; linear spring

1. INTRODUCTION

The objective of paper is the proposal of a new foot structure for biped robot. The biped walking robot is a multi-body system and has complex dynamics. The biped robot performs its locomotion relatively to the ground while it is keeping its balance and not falling down. Moreover, the biped robot is mainly made by a porous material which is a kind of flexible materials. Therefore, it is very difficult for the biped robot moving stably. In walking process, the first contact between feet and ground is specially important because of the appearance of GRF which impacts on two feet of the biped robot and makes the biped robot instable. In this paper, we added two linear springs to each foot of the biped robot. Ankle joints have been built using springs and mechanical constraints which gives a flexibility of joint within a certain range. As a result, ankle joints are passive ones. The proposed foot has the following advantages. 1) Stabilization of contact foot. 2) Absorp-tion of landing impact. The addition of springs can also increase the efficiency of the resulting gait. The biped robot may be able to exhibit more 'natural-looking' gaits. Through this idea, we designed 3D models and simulated multi-body dynamics by Adams View software, which is the most widely used multi-body dynamics and motion analysis software in the world. Control data is constructed by basing on analysis of human's gait. Primary parameters for linear springs including stiffness coefficients are determined through the simulation runs. The biped robot has no upper half of the body, so its structure has a negative effect on dynamic walk for the reason that a whole Centre of Mass (COM) position is low. For increasing the stability of the biped robot in walking process, we also implement the weight to enhance the position of COM. The simulation results show that walking with linear springs was more efficient than the same action without springs.

2. GROUND REACTION FORCE

In physics, and in particular in biomechanics, GRF is the force exerted by the ground on a body in contact with it [1]. For biped robot, GRF can result in moment to it around COM. This makes biped robot unsteady and even fall down when it walks on the ground.

In walking process of robot, we divide a step into two phases: single support phase and double support phase. Loading response of gait is the double support period between initial contact and opposite off. During this period, the foot is lowered to the ground by plantar flexion of ankle as depicted in Fig. 1. The GRF increases rapidly in magnitude, its direction being upwards [2]. This is the most dangerous period for the balance of the biped robot.

3. ANALYSIS OF HUMAN'S GAIT

To generate the robot's gait pattern which looks natural like a human gait, the control parameters of the biped robot are determined by analyzing the human gait and extracting the control parameters from the human joints [3].

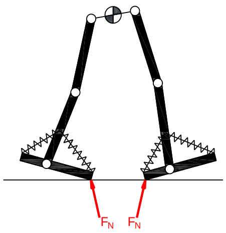
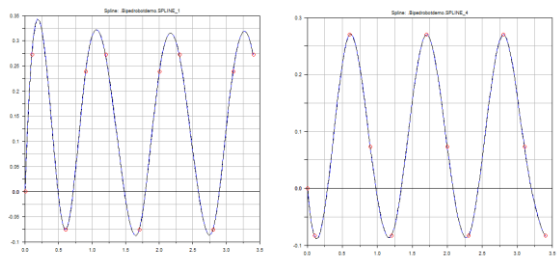
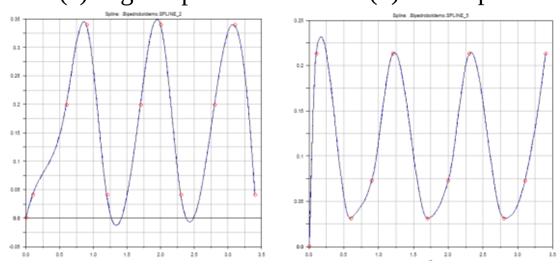


Fig.1: Ground reaction force at initial contact

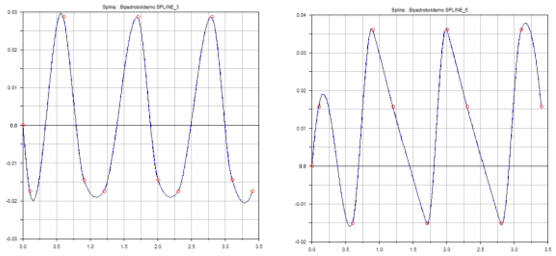
Human's gait is composed periodically of double support phase and single support phase. The principle to create gait function for biped robot will be presented as follow. Firstly, we estimated that the gait pattern would be based on the human walking cycle. From human's joint angle motion graph in sagittal and frontal planes, we collected many points. After that, we designed spline for simulation through these points as shown in Fig. 2 and Fig.3



(a) Right hip (b) Left hip



(c) Right knee (d) Left knee



(d) Right ankle (e) Left ankle

Fig.2: Sagittal plane gait pattern

4. BIPED ROBOT MODEL

We have designed two biped robot models to test walking behaviors by using multi-body dynamics simulation software, ADAMS (MSC software, USA).

4.1 The First Model

Our biped robot has 10 degree of freedom. It is designed base on dimensional ratio of human body. The segment parameters are given in Table.1. The 3D model is presented as shown in Fig. 4a

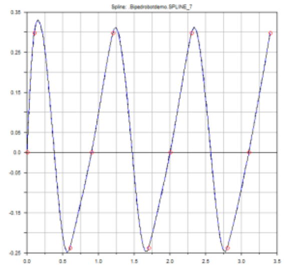
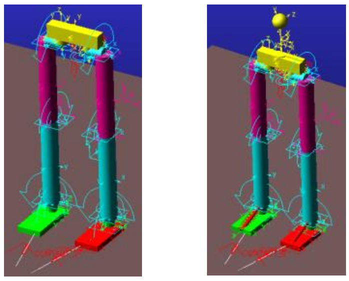


Fig.3: Hip and Ankle gait pattern by frontal plane

Table.1: Feature value of the subject's links.

Link	*Length (mm)*	*Weight (Kg)*
Trunk	50	0.56
Thigh	310	0.197
Shin	310	0.197
Foot	150	0.27

Link	*Inertia ($Kg.mm^2$)*		
	Ixx	*Iyy*	*Izz*
Trunk	3553.24	3132.05	1578.63
Thigh	1193.28	1193.28	82.70
Shin	1193.28	1193.28	82.70
Foot	688.5	515.25	191.25



(a) The first model (b) The second model

Fig.4: Two models of biped robot

4.2 The Second Model

In the second model of biped robot, we upgraded two points in comparison to the first model. The first point is to add two linear springs to each foot of biped robot. Consequently, ankle joints are passive ones. In the following point, a compensation weight was carried in the part of the upper half of the body to heighten the COM position as shown in Fig. 4b

5. SIMULATION

In this simulation, one cycle of walking is set to 1.2 seconds. We simulate the biped robot in three cycles which takes 3.6 seconds. One step takes 0.01 second, thus the number of total step is 360 steps.

Stiffness coefficients of linear springs are empirically determined by using the "try and error" method. Range of stiffness coefficients which was investigated: 0.025-0.075 N/mm, was chosen to obtain reasonable size of the feet [4]. Biped robot dynamic's simulation was performed and simulated results are shown in Fig. 5

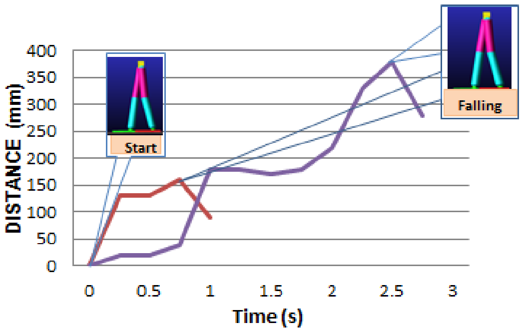


Fig. 5: Biped robot dynamics simulation results

Figure 5 describes the maximum distance of the biped robot walking on the ground in the same simulated conditions. Specifically, the maximum distance in the 1^{st} model reached only about 150 millimeters at 0.72 second. By contrast, the maximum distance in the 2^{nd} model significantly increases to roughly 380 millimeters at 2.56 seconds when the stiffness coefficient is 0.057 N/mm. It surpasses 1^{st} one by approximately three times. However, in some periods, the line graph is horizontal direction. For the reason that the biped robot slips on the ground.

6. CONCLUSION

This study is to propose a new foot structure using linear springs to improve walking ability for biped robot. Through simulation by Adams view software, we proved walking behavior of biped robot. However, that stable walking can be performed with a limitation in walking distance. Sometimes, biped robot trends to slip on the ground. Thus, it is necessary to do further improvement of stable walking.

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Nguyen Van Tinh received his B.E. (2012) from Hanoi University of Science and Technology, Viet Nam. He is a master student of Graduate School of Engineering and Science, Shibaura Institute of Technology. His current interest includes gait optimization for a biped robot.

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