THE EFFECT OF TOE MECHANISM FOR SIMULATION OF SMALL BIPED WALKIN ROBOT BY GAIT GENERATION

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ABSTRACT

The researches of biped robot have a long history and continuation. One important research and very basic movement is walking. However, the present research of biped robot is still far from proposing a solution which generates a level of flexibility and reliability gait pattern that would enable practical walking. To solve its problem, in this paper, we consider the feet of the robot which is one of the most important points as human feet in order to improve the flexibility of robot movement from heel to toe. The design of the various components of the robot feet, its flexibility and stability are excellent although this gait is not suitable for a quick walk. In this study, we introduce feet which have the toe mechanism to a small biped robot through inspiration from its adaptive walk. In the toe mechanism, we want to reduce the power consumption of the robot, therefore spring-damper is used instead of the sensor.

Keywords: biped robot, gait, toe mechanism

1. INTRODUCTION

The researches of humanoid robot and biped robot have a long history and continuation. One important research and very basic movement is walking. However, the research present of biped robot is still far from prosing a solution which generates a level of flexibility and reliability gait pattern that would enable practical walking on the variety of rough ground humans negotiation with the easiness on a regular basis.

To solve its problem, in this paper, we consider the feet of the robot which is one of the most important points as human feet in order to improve the flexibility of the robot movement from heel to toe. The design of the various components of the robot foot such as heel tiptoe or big toe, its flexibility and stability are excellent although this gait is not suitable for a quick walk.

Until recently, the studies of gait analysis for walking biped robot are incessant. Zhe Tang et al. have proposed an optimization for humanoid walking based on Genetic Algorithm (GA) base optimization for humanoid walking (Zhe et al. 2006). Lingyun Hu et al. have presented bipeds gait optimization using spline function based on probability model (Lingyun et al. 2006). These studies are about the gait optimization of biped robot. Furthermore, a natural human walking was proposed in tiptoe mechanism for biped robot. Y. Xiang et al. have presented optimization based dynamic human walking prediction (Xiang et al. 2007) which were studied an optimization-based approach for simulation of the motion of a digital human model. A model had 55 degrees of freedom which included tiptoe joints. Nandha Handharu et al. have proposed gait pattern generation with knee stretch motion for biped robot using toe and heel joints (Nandha et al. 2008). Cheol Ki Ahn et al. have proposed development of a biped robot with toes to improve gait pattern (Cheol et al. 2003), the gait pattern of the robot with toes was compared to the robot without toes by 3D graphical simulation. Shuuji Kajita et al. have proposed zero of moment point (ZPM) based running pattern generation for a biped robot equipped with toe spring (Shuuji et al. 2007). Abovementioned research was based on flat plate and there is no comparison between results obtained from a different foot.

In addition, there are some studies which related to framework for biped robot locomotion. S. Ali A. Moosavian et al. have proposed the introduction of a cartesian approach for gate planning and control of biped robots and implementation on various slopes (S. Ali A. Moosavian et al. 2007). Naoya Ito and Hasegawa Hiroshi have presented a robust optimization uncertain factors of environment for simple gait of biped robot (Naoya and Hasegawa 2007), to optimize the gait for biped robot by using Simulated Annealing (SA). The robust optimization considered random values as floor of fiction and restitution. Yu Zheng et al. have proposed a walking pattern generator for biped robots on uneven terrains (Yu et al. 2010), these approaches were more general and applicable to uneven trains as compared with prior research methods based on the ZMP criterion. Abovementioned were used without toes mechanism model.

In this study, to get flexibility and reliability of gait pattern, we introduce feet which have the toe mechanism to a small biped robot through the inspiration of its adaptive walk. In the toe mechanism, we want to reduce the power consumption of the robot therefore spring-damper is used instead of the sensor.

This paper presents the design of foot mechanisms of biped robot which have effects on walking by gait generation method. This study is the prior step for the optimization step.

2. METHODOLOGY

2.1. Simulation Model

In this paper, a robot model is simulated on flat plate as friction constant by basing on KHR-3HV model. The robot is shown in Figure 1. It has 10 RC-Servo motor under the hip and has a mass of 1.5 kg. The simulation uses the same degree of freedom on these joints.

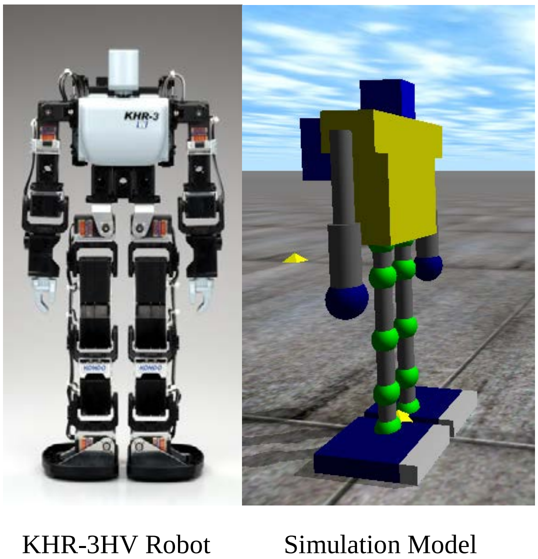


Figure 1: KHR-3HV Robot And Simulation Model

Several researches of toe joint utilization in bipedal locomotion have been proposed such as, 1) passive toe joints in order to achieve stable feet lifting, 2) toe joints that are both actively and passively control for less energy consumption walking and 3) active toe joints for stepping up stairs. In this study, to get flexibility and reliability of gait pattern, we introduce a passive toe mechanism to a small biped robot which is shown in Figure 2.

2.2. Simulation Based Design (SBD)

The design concept of the toe mechanisms to create models from the bone structures of the human foot and support force area on the foot are shown in Figure 3 and Figure 4, respectively.

In Figure 3, the bones of the toes are called the phalanges. The phalanges are jointed to the 5 metatarsal bones. Behind the metatarsal bones are a series of smaller bones known as the tarsal bones. The heel bone is called the calcaneus, which is connected to the talus bone (the largest bone of the ankle) walk. (http://www.chakras.org.uk)

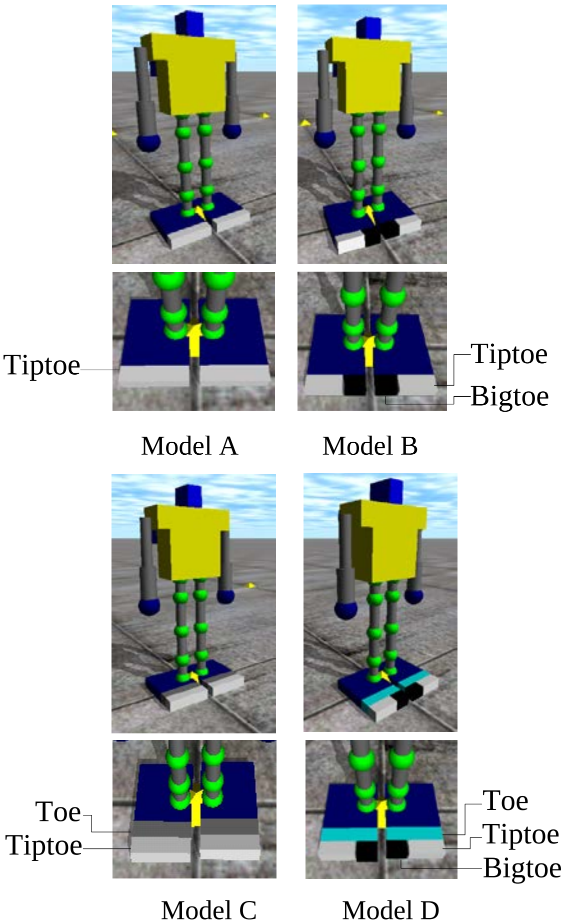


Figure 2: The Simulation Models With Toe Mechanism
Model A: The Simulation Model With Tiptoe
Model B: The Simulation Model With Tiptoe And Big Toe
Model C: The Simulation Model With 2-Tiptoes
Model D: The Simulation Model With 2-Tiptoes And Big Toe

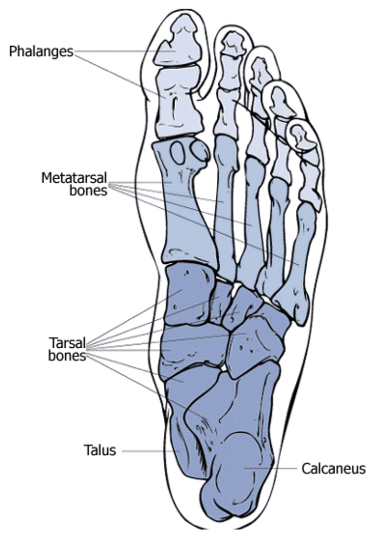


Figure 3: A Foot Bone Structures

In Figure 4, Perry J. (Perry, 1992) shows the sequence of foot support areas during stance phase. The black area is the position where supports forces areas. We used in a conceptual design to make toe mechanism model.

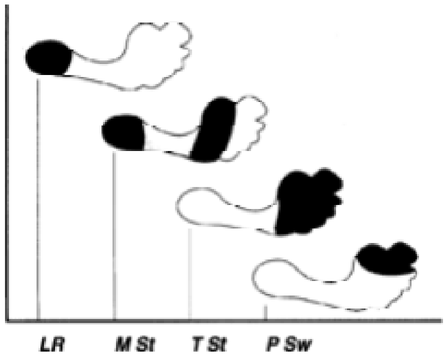


Figure 4: Human Sequence Of Foot Support Areas During Stance Phase (Perry, 1992)

2.2.1. Definition of the gait function

This paper is assumed the robot walks based on the gait function. Therefore, the function is defined based on a human gait pattern that focused on the walk cycle. To express this periodic cycle, the function which generated the gait is defined as follows:

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

Where t is time, ω is angular velocity, i is number of each joint a, b, c, and d are coefficients of generating the gait for various wave. The gait for biped robot is changed by operating these coefficients.

2.2.2. Adaptation to simulation

The sampling time of the function to generate the gait is quarter a gait cycle. The generated angle data is allocated the joint for position control value. A joint moves with a constant velocity between control points. In this simulation, *1 cycle* of walking is defined *1.2 seconds*. Thus, angular velocity is given as follows:

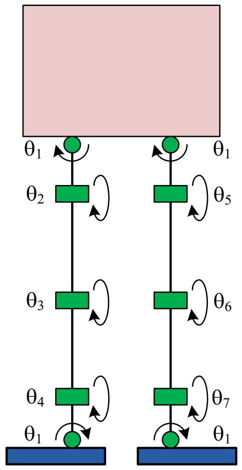
$$\omega = \frac{2\pi}{1.2} \qquad (2)$$

3 cycles of walking time is *3.6 seconds*. And the total time is *7.0 seconds* taking *3.4 seconds* in order to check after walking stability. In this simulation, *1 step* takes *0.001 seconds,* thus the number of total step is *7000 steps*. For example, a gait pattern of a joint angle which is made by the gait function.

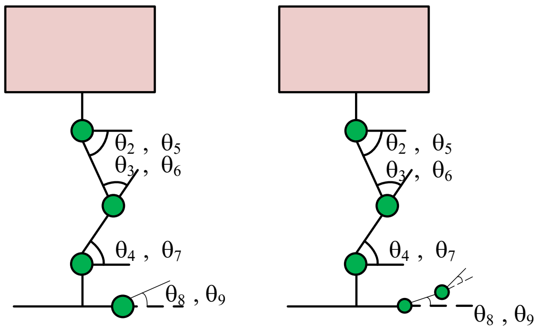
The position of the joint is shown in Figure 5. In addition, because of the servomotor of the joint of the biped robot, its joint can be rotated by *60 degree* every *0.14 seconds*. The rotate directions for each joint are shown in Table 1. Knee joints do not rotate to backward direction from standing. Thus, these joint are stricter rotating to minus angle as follows:

$$\theta_3 = \begin{cases} 0 & if \;\; \theta_3 < 0 \\ \theta_3 & if \;\; 0 \le \theta_3' \end{cases} \qquad (3)$$

$$\theta_6 = \begin{cases} 0 & if \;\; \theta_6 < 0 \\ \theta_6 & if \;\; 0 \le \theta_6' \end{cases} \qquad (4)$$



Font side view



Right side view

Figure 5: The Link Of Model

Table 1: Parameter And Rotation Direction

Parameter	Leg	Joint	Rotation Direction
θ_1	Both	Hip and Ankle	Side-to-Side
θ_2	Right	Hip	Backward-and-Forward
θ_3	Right	Knee	Backward-and-Forward
θ_4	Right	Ankle	Backward-and-Forward
θ_5	Left	Hip	Backward-and-Forward
θ_6	Left	Knee	Backward-and-Forward
θ_7	Left	Ankle	Backward-and-Forward
θ_8	Right	Toe	Backward-and-Forward
θ_9	Left	Toe	Backward-and-Forward

The horizontal surface is applied for the ground surface of the simulation. Moreover, for the ground surface, friction and restitution coefficients are defined as *1.0* and *0.0*, respectively.

2.2.3. The design of simulation experiments

The design of simulation experiments, design variable vectors can generate form gait function Eq. (1) to each joints expect for the toe joint because we are determined to be passive toe mechanism, design variable vectors shown in Eq. (5) and have degree of freedom (DoF) is 28.

$$\theta_i = [a_i, b_i, c_i, d_i]; \qquad (i = 1,2,3,4,5,6,7) \qquad (5)$$

$$\theta_{all} = [\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7]$$

In order to the model move forward and on the path, by the end of the simulation we define the following conditions as Eq. (6) and (7). When X_d are the distances at the side under *±30 [mm]* in Eq. (6) and in Eq. (7) R_d is the angle to the rotation direction under ±*5 degree* and distance Y_d not exceeding *200 [mm]* to prevent the slip. When X_d, Y_d *and* R_d are denoting the distances and rotation of model's center of mass (CoM) shown in Figure 6.

$$-30 \le X_d \le 30\ [mm] \quad if \quad t = 7.0\,[sec] \qquad (6)$$

$$-5.0 \le R_d \le 5.0[deg] \quad if \quad t = 7.0\,[sec] \qquad (7)$$

$$Y_d \le 200 \qquad [mm] \quad if \quad t = 7.0\,[sec] \qquad (8)$$

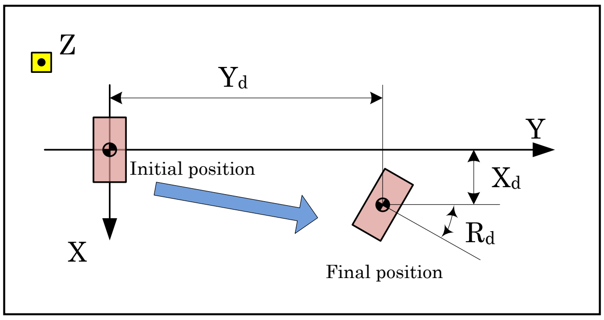


Figure 6: Overview Of The Simulation

3. RESULTS OF THE SIMULATION

All simulation models of small biped robot with passive toe mechanism can walk. The results are shown in Table 2.

The results, model A and model B are according to the condition. The maximum distance *(Y_d)* is model B *119 [mm]*, minimum distance side (X_d) is *-5 [mm]* and rotation *(R_d) = 3.1 [deg]*. The latter is the model A which distance *(Y_d)* is *86 [mm]*, distance side (X_d) is *-25 [mm]* and rotation *(R_d) = 4.2 [deg]*. On the other hand model C and model D, The results are not as good as expected. The trajectory of the robot's CoM is compared model A, B, C, and D as shown in Figure 7, 8 and 9.

Table 2: The Simulation Results

	Distance		Rotation
Model	**Y_d (mm)**	**X_d (mm)**	**R_d(deg)**
A	86	-25	4.2
B	119	-5	3.1
C	49	-11	12.0
D	0	-64	23.2

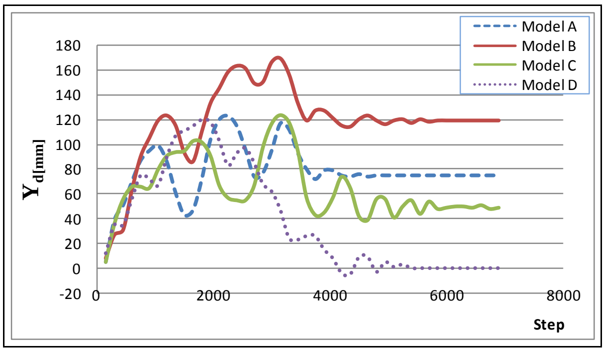


Figure 7: The Distance Trajectory (Y_d) Of The Robot's Center Of Mass (CoM)

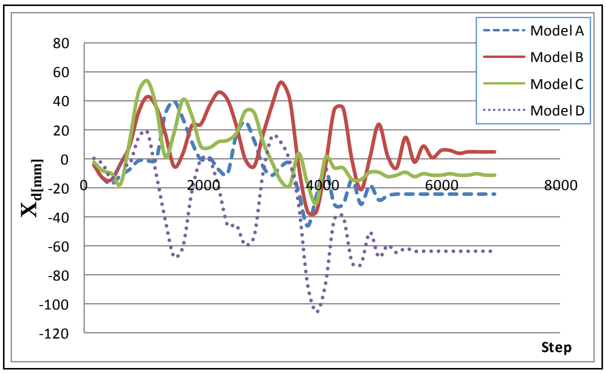


Figure 8: The Side Trajectory (X_d) Of The Robot's Center Of Mass (CoM)

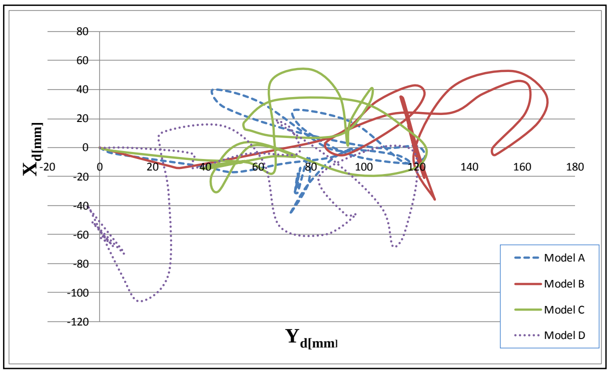


Figure 9: The Trajectory Of The Robot's Center Of Mass (CoM)

The trajectory of the robot's CoM in Figure. 7, 8 and 9. In model A, when we consider the walking step found that the trajectory of model B is larger and similar to human walking trajectory (Gait Analysis Based on Joint Moment 1997*)* but during into stable also to swing a lot. The other side, the trajectory of model C and model D the trajectories are small and walking is awkward.

Waveforms of the gait functions assigned to joints are compared model A, model B, model C and model D as shown in Figure 10-16.The widely of waveform of hip and ankle roll-joints $\theta_1(t)$ less changed and that similar to cosine function. However, the values of the other joints (Figure 11-16) that are distribute to adapt walking ability without falling. This is a one thing from the effects of the difference toe mechanisms in this study.

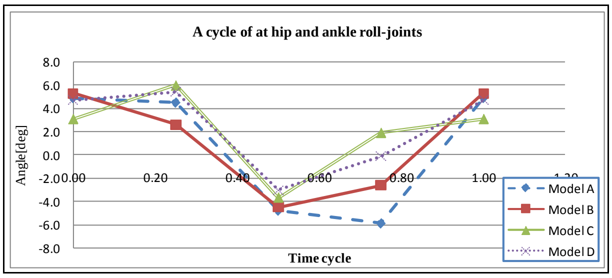


Figure 10: A Cycle Of Gait Function θ_1(t) @ (Hip And Ankle)

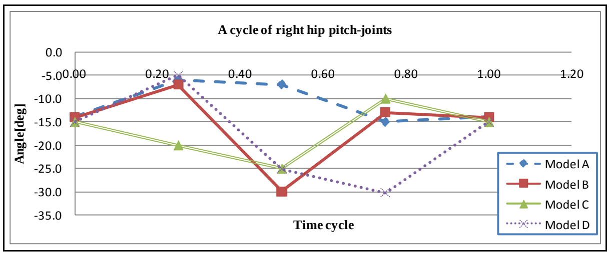


Figure 11: A Cycle Of Gait Function θ_2(t) @ (Hip Pitch-joint)

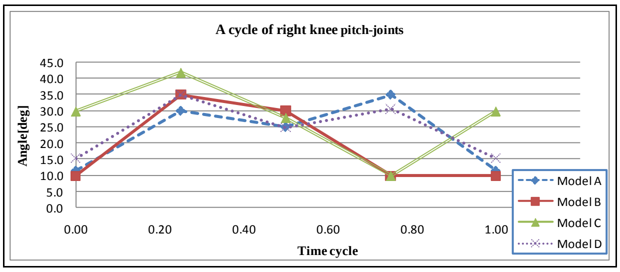


Figure 12: A Cycle Of Gait Function θ_3(t) @ (Knee Pitch-joint)

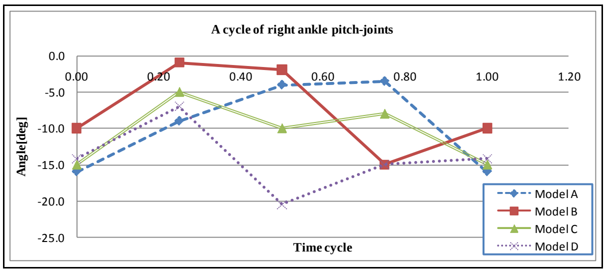


Figure 13: A Cycle Of Gait Function θ_4(t) @ (Ankle Pitch-joint)

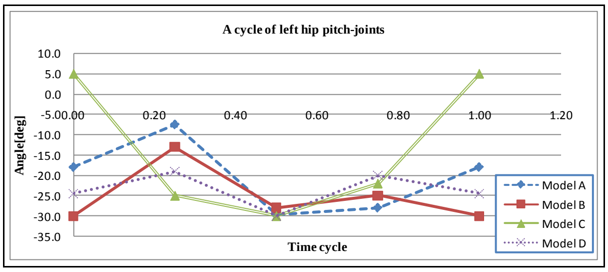


Figure 14: A Cycle Of Gait Function θ_5(t) @ (Hip Pitch-joint)

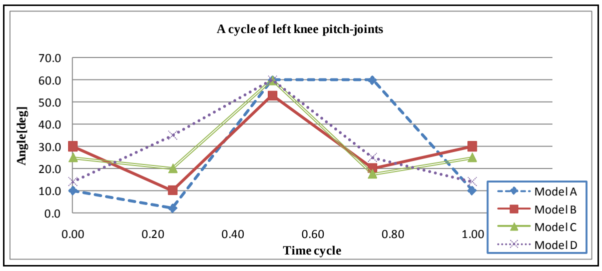


Figure 15: A Cycle Of Gait Function θ_6(t) @ (Knee Pitch-joint)

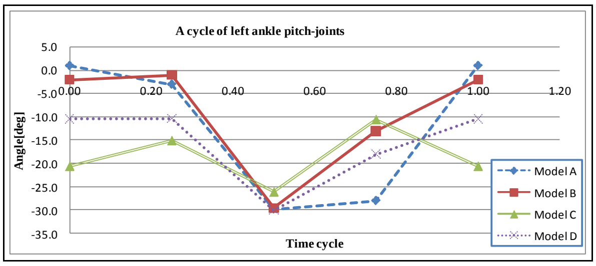


Figure 16: A Cycle Of Gait Function θ_7(t) @ (Ankle Pitch-joint)

4. CONCLUSION

We discussed a simulation base design (SBD) of small biped robot with toe mechanism walking on flat ground. The simulation of robot can walk. The simulations model A and B obtained a good gait pattern while model C and model D the results not as expected especially in model D which composites than other model and there have a strong impact. Therefore we will continue to experiment, improve and resolved for applied to real small biped robot.

As our next target, we will resolve in simulation of each model and used optimization method in order to achieve the objective function. Finally, applied to real small biped robot walking will be test as an experiment.

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