Brake Motion Control for Quadruped Hopping Robot by Using Reference Height Control System

A.M Kassim[1], T. Yasuno[2], Sivaraos[1], H.I Jaafar[1]

Abstract – *In this paper, the generation of brake motion control for our developed quadruped hopping robot while moving on two dimensional space by jumping continuously is discussed. the braking motion method which is approached is by applying the reference height control system to create the differences of front leg and back leg while making moving performance and correct the body posture which has inclined to make the quadruped hopping robot jump vertically while braking performances. On the other hand, this approached method can be used as the collision-avoidance behavior for the quadruped hopping robot. The MATLAB/Simulink model is used in order to conduct the pattern generation of quadruped hopping robot. As the result, effectiveness of approach method is confirmed to generate brake motion control of quadruped hopping robot while making continuous jumping vertically.*

Keywords*: quadruped hopping robot; CPG networks; moving and braking motion control*

I. Introduction

Bio-inspired for robot locomotion has been greatly studied by a lot of researchers in the world in these three decades. The types of locomotion that have been studied mostly on legged type, crawling type and flying type locomotion. It is because of the mobility and adaptive motion control that can be achieved by using the bio-inspired method. However, by using this type of locomotion still have a lot of challenges that have to be solved such as complexity of control system, robustness and adaptive motion in various environments and complexity of robot construction. On the other hand, one of the locomotion that also has been focused is jumping type locomotion. Jumping type robot also can be classified in two kind of mechanism which is one big jump and rhythmical jump called hopping type mechanism.

M.H Raibert who has done research on one legged hopping robot is the main contributor of hopping robot research [1]. The first hopping robot invented consists of body and leg which is equipped with a pair of pneumatic actuators to exert torque between the leg and the body about to hip. Then, Koditscheck and Buhler have discovered the discrete dynamic system theory which analyzes the dynamics of a simplified hopping robot which focused on the vertical movement only [2]. Besides, I. Murakami et al. has done his research on hopping robot which control the hopping and moving motion by using the linear DC motor and the gyroscope for attitude control. The linear DC motor was designed into the body part and the leg part of the hopping robot and constructed the direct-drive hopping mechanism [3].

In addition, Okubo et al. has introduced the design of jumping machine using self-energizing spring. His research has produced a machine or robot which can achieve high jumping performance by using small output actuators [4-5]. Moreover, Tukagoshi et al. has studied on numerical analysis and design for higher jumping rescue robot by using a pneumatic cylinder. They had developed the leg in rotor type robot which can use in flatted smooth surface (wheeled locomotion) and overcome the irregular surface (jumping locomotion) [6-7]. Hence, the effectiveness of bio-inspired locomotion of robot also can be implemented by using bio-inspired control system such as neural networks, neural oscillator and etc that consisted non-linear control system as main brain of robot.

On the other hand, physiological experiments suggest that basic locomotors patterns of most living bodies such as walking, flapping, flying and swimming are generated by CPGs which generates rhythmic activities [8-9]. CPG is neural networks that can endogenously produce rhythmic patterned outputs; these networks underlie the production of most rhythmic motor patterns. The periodic activities of the CPG which are initiated by a burst from the higher motor centre induce the muscle activities. After the initiation of the locomotion, the activities of the CPG are affected by sensory signals which show the bending of the body and so on [10]. The proactive sensory feedback plays an important role in the shaping and coordination of the neural activity with the mechanical activity.

Additionally, neurophysiologic studies of insect locomotion suggest that sensory feedback is involved in patterning motor activities and that is more than modulation of the centrally generated pattern [11-12]. The construction of useful legged type locomotion comes from the system which is able to control joint motion, monitor and manipulate balance, generate motions to use known footholds, sense the terrain to find good footholds and calculate negotiable foothold sequences. Furthermore, Taga proposed a walking motion control mode in which neural oscillator interact with the sensory feedback signals from the musculoskeletal systems [13-14]. Then, by using the concept of walking motion control model suggested by Taga, Kimura proposed a method of structuring the coupling of neural and mechanical systems for the implementation of autonomous adaption through the irregular terrain [15]. Besides that, Son et al. proposed a CPG model including the motor dynamic characteristics of an actuator for the purpose of implementing generation adaptive gait patterns for a quadruped robot under various environments [16]. Meanwhile, Kondo et al. has developed the quadruped hopping robot which is used central pattern generators (CPGs) as pattern generator in order to generate the continuous jumping performance while control the stability of body balance [17-19].

In this paper, the generation of moving and braking motion control for the developed quadruped hopping robot while jumping continuously on two-dimensional space is proposed. Here, the reference height control system is applied to control the reference height for each leg independently[20-22]. Therefore, the differences height of front legs and back legs to generate the moving performance and correcting the body posture which has inclined to make the quadruped hopping robot jump vertically can be created. On the other hand, the effectiveness of Central Pattern Generator(CPG) network to keep the stability of quadruped hopping robot and avoiding it from tumble ahead also evaluated.

II. Developed Hopping Robot

II.1. Robot Construction

Figure 1 shows the developed quadruped hopping robot construction (overall length is 49cm, overall width is 49cm, overall height is 37cm and the total weight is 9.1kg). The quadruped hopping robot consists of the legs. Each leg is composed with a DC geared motor (12V, 200min^{-1}, 0.0098Nm), a crank and a spring attached to the crankshaft. Then, each leg is connected to the shared platform.

Fig. 1 Quadruped hopping robot

The developed quadruped hopping robot is developed by a DC geared motor which is driven by using DC amplifier and connect to the crank which used to push the platform.

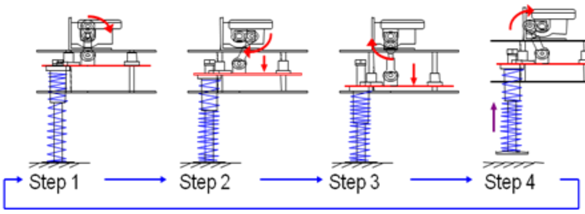


Fig. 2 Hopping mechanism

As shown in Figure 2, the hopping mechanism of the quadruped hopping robot can be achieved respectively. Here, the motor torque is converted to the periodic force to the spring and make a periodical hopping motion of hopping robot as the basis of the principle hopping motion. The continuous hopping of quadruped hopping robot could be generated by using floor repulsive force when the suitable force was applied to the spring at the suitable time.

II.2. Experimental Setup

Figure 3 shows the experimental setup to evaluate the quadruped hopping robot. The proposed CPG network is expressed using a MATLAB/Simulink model on a host computer. Then the model, built by a Realtime workshop, is downloaded to xPC target computer. The xPC target computer is run by using a realtime OS. The position of the center and each leg are measured using ultrasonic sensors which are used as sensory feedback signals of the CPG. The sampling time is set for controlling this experimental setup is 0.01s.

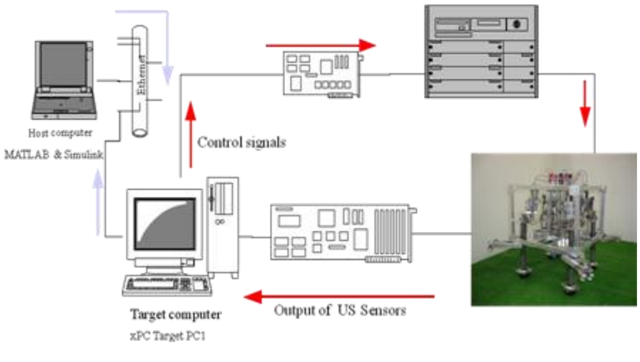


Fig. 3 Experimental setup

III. System Configuration

III.1. CPG Model

Figure 4 shows the conventional CPG model which is proposed by Taga[9]. The CPG model is modified to a block diagram of the CPG model which is shown in Figure 5. Here, the inhibitory unit of the CPG includes the mechanical dynamics of the leg. Parameters u_e and u_i denotes the internal state of the excitatory unit and the inhibitory unit, b and c denotes the intrinsic excitatory and inhibitory coupling parameter, a denotes the excitatory coupling factor while B_0 denotes the constant bias input. The output of the inhibitory unit corresponds to the platform position of each leg and is applied to the excitatory unit through a nonlinear function $\tan^{-1}(u_i)$ and the feedback gain b which formulated as

$$\tau_e \frac{du_e}{dt} = -u_e + a\tan^{-1}(u_e) - b\tan^{-1}(u_i) - B_0$$

$$u_i = f(K_a c\tan^{-1}(u_e) - d)$$

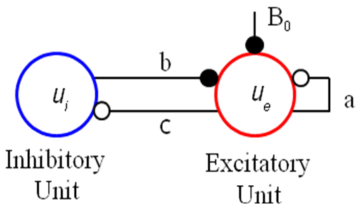


Fig. 4 Conventional CPG model

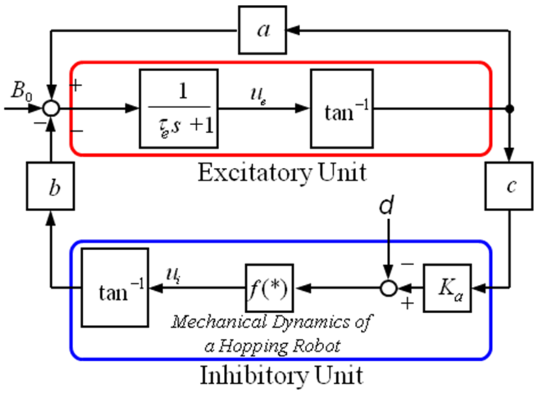


Fig. 5. Block diagram of CPG model.

where $f(*)$ is the mechanical dynamics of the hopping robot's leg, K_a is the gain constant of the DC amplifier and d is the external disturbance which is the floor repulsive force in this case. By arbitrarily hanging the coupling parameters a, b, c, the time constant τ_e and the mechanical dynamics of the hopping robot, the CPG can change the amplitude and the frequency of internal states u_e and u_i.

III.2. Reference height control algorithm

Fig. 6 shows the block diagram of the reference height control algorithm for one leg of developed tripod hopping robot. This block diagram is built by using MATLAB/Simulink tool. This system consists of maximum height detector, the PI controller and the CPG. By using the proposed control algorithm, the tripod hopping robot can keep the hopping motion and control the hopping height to achieve the reference hopping height by adding a feedback loop through a fixed gain PI controller. The joint actuator is driven by the control system in order to realize the reference hopping position generated by the PI controller on each leg.

Deduction of sensory feedback signal h_{max} of the ultrasonic sensors on each legs from the reference height h_{reff} gives the value of steady state error h_{diff} which represents the command signal. In control engineering, a PI controller is a feedback controller which drives the plant to be controlled with a weighted sum of error h_{diff} and integral of that value. The integral term in PI controller causes the steady state error to be zero for a step input.

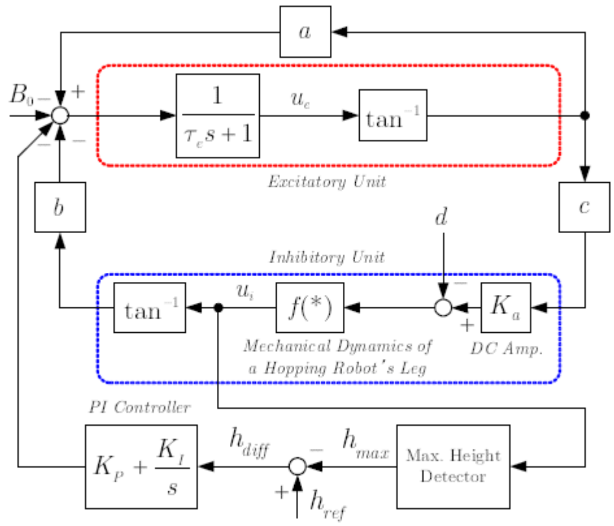
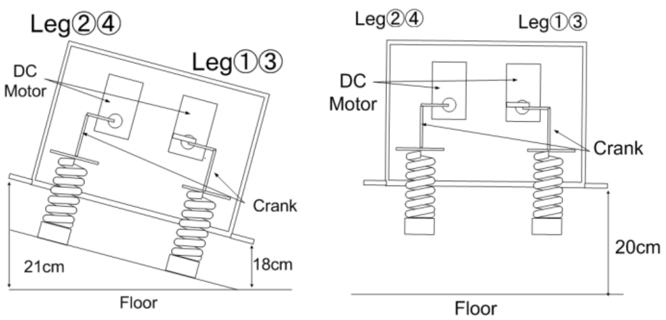


Fig. 6. Block diagram of reference height control system

III.3. Moving and Braking Motion

Here, the proposed moving and braking method which is used in order to control the moving and braking system for quadruped hopping robot is mentioned. The reference height control system is applied in order to set the desired hopping height for each leg for quadruped hopping robot. The reference height control system is used to create the differences height of front legs and back legs to make body posture incline ahead for moving performance. In addition, the body posture of quadruped hopping robot will be corrected in order to jump vertically again by set the reference jumping height for each leg to same reference height. Figure 7 shows the moving and braking condition. The correction of body posture which has inclined by setting the reference height for all legs to 20cm could make the quadruped hopping robot jump in one dimension called braking motion.

The whole experiment is conducted in 60sec which in the first 10sec period, the reference hopping height is set for all legs to 20cm in order to maintain the oscillation of hopping performances, in advance. Then, after 10sec until 40sec, the moving performance is set where leg 2 and 4 is set as back leg and the reference height is set to 21cm while leg 1 and 3 is set as front leg which the reference height is set to 18 cm. Therefore, started from 40sec to 50sec, the proposed braking motion performance where all legs will be set to same reference height at 20cm. After that, the moving performance is set again from 50sec to 60sec to evaluate the effectiveness of proposed braking motion control method.



Moving motion   Braking motion

Figure 7 Robot posture for moving and braking motion

III.4. CPG Networks

The quadruped hopping robot can continuously jump by applying the same periodic force to each spring of robot and the cooperative oscillation among the CPGs is required. By using the ring-and-cross type CPG network, the stable, continuous and rhythmical hopping performance is obtained. In addition, Figure 8 shows the reference height control system is included into CPG model in each leg in order to control the hopping height of each leg independently.

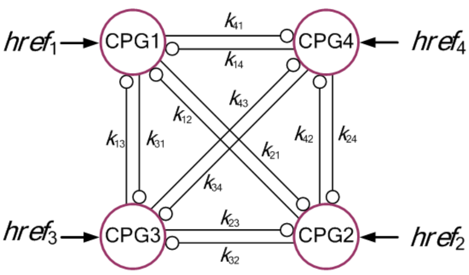


Figure 8 Ring cross type CPG networks

IV. Experimental results

In order to evaluate the validity of proposed moving and braking motion control, the experiment is conducted. Here, the internal parameters of CPGs are set to the typical value as a=0.1, b=2, c=1, B_0=0.01, = 0.1, f=0.1 and the PI controller's gains are set as K_P = 5.5 and K_I = 0.4 in advance, in order to generate the efficient hopping performances. The experimental results shows the data of jumping height, command signal, difference (steady state error), feedback signal, for each leg while conducting the experiments. Figure 9 shows the last 30 sec which was conducted the moving motion (30- 40 sec), braking motion (40 - 50 sec) and moving motion (50 - 60 sec). As the results, the changing of control signals, current values and hopping height values in order to generate the successful moving and braking motion at the period of 40 - 50 sec. For the braking performance, the control signals for leg 1 and leg 3 are increasing to -10V to achieve the reference height which have set to 20cm while current values are increased in order to give more torque to the geared DC motor. The value for the command signal is absolute value which the -10 V equal to 10 V. The hopping height also increased from the average 18cm to 20cm. At the same time, the maximum height for leg 1 and leg 3 are increasing from 18cm to 20cm while maximum height for leg 2 and leg 4 are still remain at 20cm to make the vertical hopping motion.

However, the control signals for leg 2 and leg 4 are unchanged according to reference height which have been set for leg 2 and leg 4 are unchanged. It also can be proved by unchanged of value for current values at leg 2 and leg 4 which give same torque to the DC geared motor periodically. Consequently, the maximum hopping height for leg 2 and leg 4 which have been achieved also about 20cm at 40 to 50 sec in order to perform braking motion. after 50 sec, the moving motion is performed again and the changed on command signal and current values for leg 1 and leg 3 is changed respectively. the experiment is conducted until 60 sec only.

V. Conclusion

In this paper, the algorithm of moving and braking motion method in order to give stabilization to the developed quadruped hopping robot is proposed. Here, the effectiveness of approach method to generate moving and braking motion control of quadruped hopping robot while making continuous jumping vertically is confirmed. On the other hand, the effectiveness of CPG networks which act as a command center for the musculoskeletal system to generate the continuous hopping performances and to keep the stability of quadruped hopping robot and avoiding it from tumble ahead also obtained.

In the future, we aim to investigate more possibilities of quadruped hopping robot to achieve higher jumping position than the current achievement in order to give higher speed.

Acknowledgements

This research was supported by grant from Universiti Teknikal Malaysia Melaka award no. FRGS/2012/FKE/TK02/03/2/F00124 S726 and also technically support by the member from The University of Tokushima, Japan.

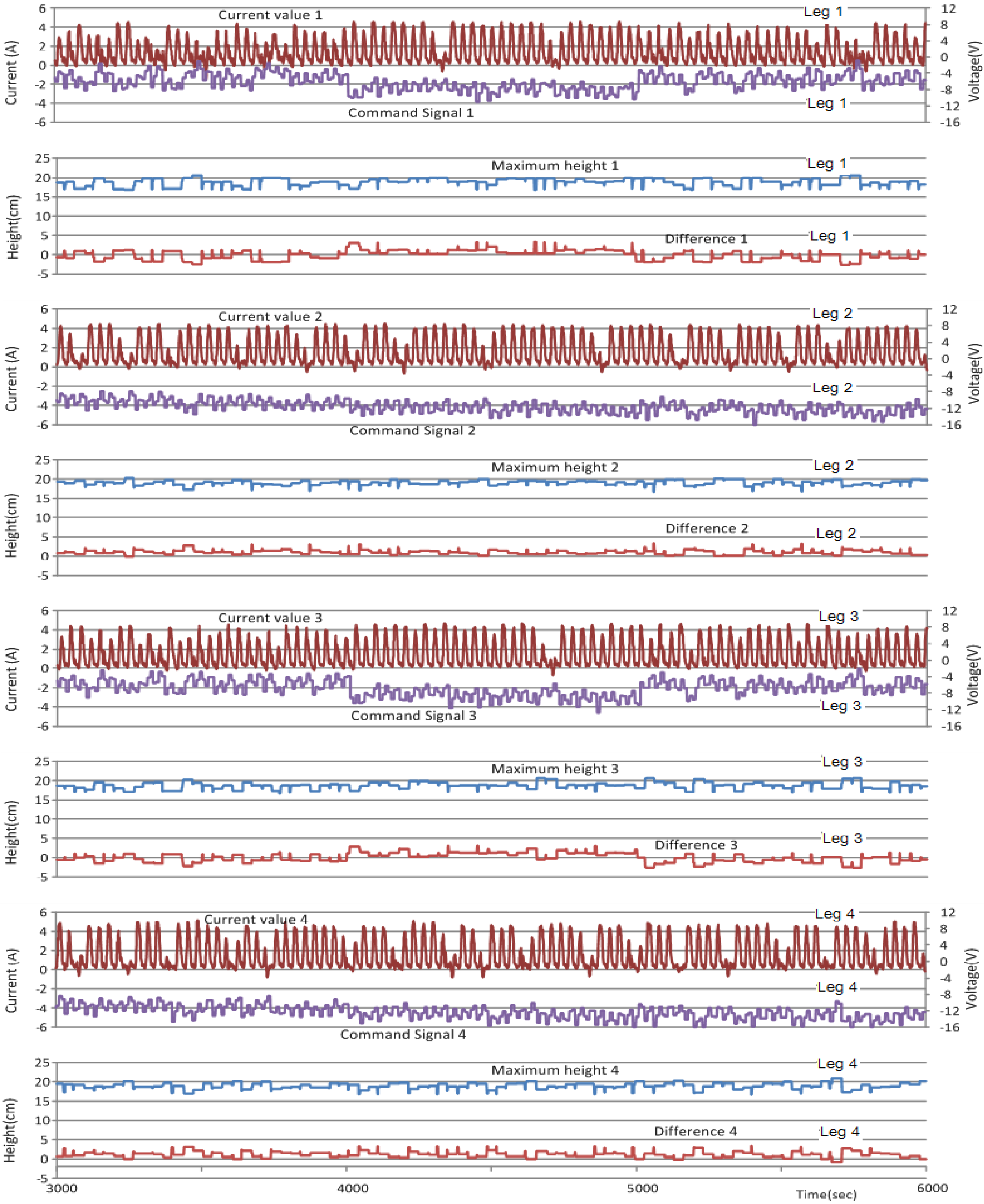


Figure 9 Moving and braking performances from 30 to 60 sec

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