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Two-Dimensional Moving Control of Quadruped Hopping Robot Using Adaptive CPG Networks

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Abstract

In this paper, we discuss on the generation of moving control for our developed quadruped hopping robot while jumping continuously. We approached the method which we used the reference height control system to conduct the differences of reference height for each leg of quadruped hopping robot. By using the approached method, the posture of the quadruped hopping robot will incline ahead to the direction which it wants to move. On the other hand, we evaluate the effectiveness of Central Pattern Generator (CPG) network to keep the stability of quadruped hopping robot and avoiding it from tumble ahead. We used MATLAB/Simulink model to generate the moving control in various types of motion. As the result, we confirmed the effectiveness of approached method to generate moving control of quadruped hopping robot while making continuous jumping, respectively.

Keywords: two-dimensional moving control, CPG networks, quadruped hopping robot

1. Introduction

Physiological experiments suggest that basic locomotors patterns of most living bodies such as walking, flapping, flying and swimming are generated by central pattern generators (CPGs) which generates rhythmic activities (1). CPG are neural networks that can endogenously (i.e. without rhythmic sensory or central input) produce rhythmic patterned outputs; these networks underlie the production of most rhythmic motor patterns. The first modern evidence that rhythmic motor patterns are centrally generated was the demonstration that the locust nervous system, when isolated from the animal, could produce rhythmic output resembling that observed during flight (2).

Furthermore, neurophysiologic studies of insect locomotion suggest that sensory feedback is involved in patterning motor activity and that it is more than the modulation of the centrally generated pattern. And as application of the CPG, a method of designing control systems for legged robot motion has been reported. On the basic of the definition, walking is locomotion emerging from that interaction between the environment and the body. Here, Taga proposed a walking motion control mode in which neural oscillator interact with the sensory feedback signals from the musculoskeletal systems (3) (4).

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 to irregular terrain (5). 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 environment (6). Then, to apply in quadruped hopping robot, Kondo proposed the CPG network to generate continuous jumping motion patterns (7).

In this paper, we discuss on the generation of moving control for our developed quadruped hopping robot while jumping continuously.We approached the method which we used the reference height control system to conduct the differences of reference height for each leg of quadruped hopping robot. By using this method, the posture of quadruped hopping robot will incline ahead to the direction which it wants to move. On the other hand, we evaluated the effectiveness of Central Pattern Generator (CPG) network to keep the stability of quadruped hopping robot and avoiding it from tumble ahead.

2. Quadruped Hopping Robot

2.1 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 four legs. Each leg is composed with a DC geared motor (12V, 200min^{-1}, 0.0098 Nm), a crank and a spring attached to the crankshaft. Then, each leg is connected to the shared platform.

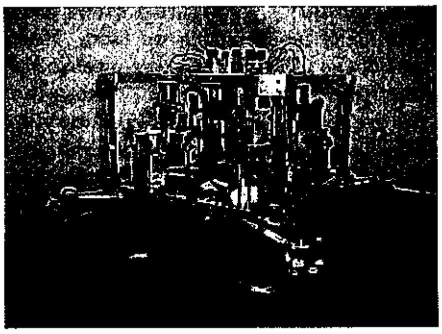

Fig. 1. Quadruped hopping robot

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

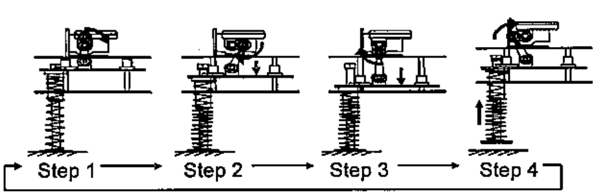

Fig. 2. Hopping motion mechanism

2.2 Experimental Setup Figure 3 shows the experimental setup to evaluate the developed 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 a 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. We also included the current sensors into the system which are used to monitor the current value which have given to each leg on each jumping motion. In this experiment, the sampling time for the control is set to 0.01 sec.

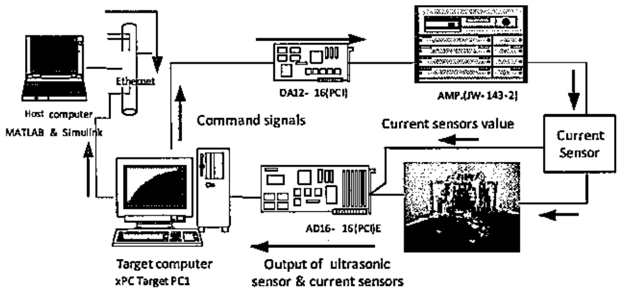

Fig. 3. Experimental setup

3. Control System Configuration

3.1 CPG model Figure 4 shows the block diagram of the CPG model which we used. Here, the inhibitory unit of the CPG includes the mechanical dynamics of the leg. Parameters u_e and u_i denote the internal states of the excitatory unit and the inhibitory unit, b and c denote the intrinsic excitatory and inhibitory coupling parameters, 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

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

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

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.

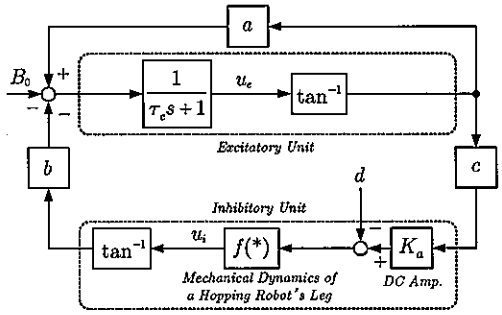

Fig. 4. Block diagram of CPG model

3.2 Reference height control system The architecture of the reference height control system for a leg is shown in Fig.5. This control system is composed of the maximum height detector, the PI controller and the CPG. By adding a feedback loop through a fixed gain PI controller, quadruped hopping robot keep the hopping motion and control the hopping height to achieve the reference hopping height. The control system drives the joint actuator of leg in order to realize the desired hopping position generated by the PI controller, respectively. The PI feedback controller receives the command signal of the target hopping position as a reference h_{ref} and receives sensory feedback signals h_{max} from the ultrasonic sensors on each legs. The differences is given to the PI controller as a command signal. In control engineering, a PI controller is a feedback controller which drives the plant to be controlled with a weighted sum of the error (difference between the ultrasonic sensor output and reference hopping height) h_{diff} and the integral of that value. The integral term in a PI controller causes the steady-state error to be zero for a step input.

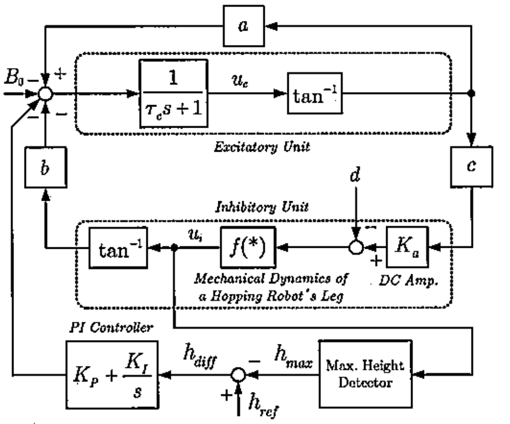

Fig. 5. Block diagram of reference height control system

3.3 CPG Networks The quadruped hopping robot can jump continuously by applying the same periodic force to each spring of robot's leg and the cooperative oscillation among the CPGs is required. Figure 6 shows the configuration of typical CPG networks. By using this ring-and-cross type CPG networks, we could obtained the stable, continuous and rhythmical hopping performances (7). In addition, we included the reference height control system with CPG model into each of robot's leg. Therefore, the hopping height of each legs can be controlled independently according to the reference height which have been set. The structure of CPG networks are illustrated in Fig.6.

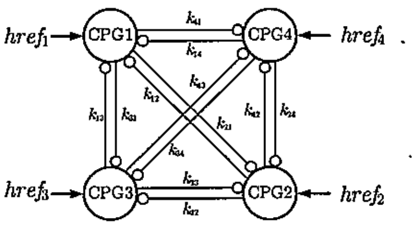

Fig. 6. Ring-and-cross type CPG networks

4. Experimental Conditions

To confirm the validity of our proposed moving method, the experiment for moving performances are conducted on two-dimensional level surface. Here, the internal parameters of CPGs are set to the typical value as $a = 0.1$, $b = 2$, $c = 1$, $B_0 = 0.01$, $\tau_e = 0.1$, $f = 0.1$ 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 motion. In this experiment, we used the reference height control system to control the desired hopping height for each leg of our developed quadruped hopping robot. We conducted the whole experiment in 50sec which in the first 5sec period, we set the reference hopping height for all legs to 20cm to get maintain the oscillation of hopping performances, in advance. Then, as well as our developed quadruped hopping robot leg's position are shown in Fig.6, we set the reference height for leg 1 and leg 3 to 18cm and leg 2 and leg 4 to 20cm in order to make the posture of hopping robot's body incline ahead to the direction which it should be move.

5. Experimental Results

In this section, the experimental results for our proposed moving method are illustrated in Fig.7. These experimental results are including 4 types of output signals such as the maximum hopping height value h_{max} on each jump which are scraped by using the ultrasonic sensors for each leg. Then, the signal of differences(steady state error) h_{diff} which are obtained from comparing the reference height h_{ref} with the maximum hopping height value h_{max} and the command signals which have been sent from DC amplifier to the DC motor of quadruped hopping robot. And the last output signal is the current sensors value which are measured by using the current sensors which we mounted on each DC motor for each leg. In Fig.7, the output signals of current sensors value and command signals are shown at the top of the figure following with the output signals of difference(steady state error) and maximum hopping height value at the second graph. Both graph are illustrated for leg 1 then following with the other leg's graphs after it. For the current sensors value and command signals graph, we are using the primary y-axis for current sensors value which the unit is Ampere(A) and the command signals are using the secondary y-axis which unit is Voltage(V). The figures for the command signals, the power voltage can be thought as the absolute value.

From these experimental results, we could see that our quadruped hopping robot are succeed to attain the reference hopping height which the reference height are set to 20cm on each leg at the first 5sec period while hopping in one-dimensional level. Then after 5sec, we could see the changing of command signals and the current sensors value in order to implement the moving performances following by the changing of reference height on each leg. Here, we could know that the leg 1 and leg 3 are trying to achieve the reference height which are set to 18cm by decreasing the power voltage value about 50% and oscillated around -4V to -8V which are supplied to the DC motor. On the other side, the power voltage value for leg 2 and leg 4 are maintained same as the first 5sec period level in order to maintain the reference height at 20cm. Here, we confirmed the achievement for leg 2 and leg 4 to attain the reference height at 20cm. At the same time, the current sensors value for leg 1 and leg 3 are decreasing cause the load value while the command signals are decreasing. Meanwhile, the current sensors value for leg 2 and leg 4 are same at the whole experiment although sometimes the current sensors value are little bit decreased periodically. The changing of current sensors value periodically was because the leg 1 and leg 3 are increased their power voltage. Therefore, the power voltage for leg 2 and leg 4 are decreasing to keep the balancing of quadruped hopping robot's body. Here, we confirmed the validity of CPG networks system which are functioning to maintain the stability of quadruped hopping robot and avoiding it from tumble ahead.

As the results for controlling the command signals, the differences(steady state error) which have been obtained from each leg are entered the PI controller system to converge the differences to be zero. Therefore, the maximum hopping height can be achieved according to the reference height which have been set. Especially, the differences for leg 1 and leg 3 are tried to converge to zero that we can see from the figure that the differences are stayed around 1cm compared to the reference height. Besides, the differences for leg 2 and leg 4 are converged to zero and successful to keep the maximum hopping height at 20cm in the whole experiment. In addition, the moving distance which have been succeed is 120cm in 50sec experimental time.

6. Conclusions

In this paper, we proposed the moving method which are using the effectiveness of reference height control system to conduct the reference hopping height on each jumping period. By setting the different reference hopping height on each leg of quadruped hopping robot, the posture of robot's body could inclined ahead to the direction which it should move. As the result, we confirmed the successful moving performances while hopping continuously and rhythmically in two-dimensional level surface. On the other hand, we also obtained the effectiveness of CPG networks which act as a command centre 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.

In the future, we aim to investigate various types of moving motion for our developed quadruped hopping robot. Besides, we try to investigate more possibilities to achieve higher hopping height than the current achievement. We also aim to include the learning algorithm we aim to acquire the CPG parameters and coupling parameters of CPG networks for hopping on an arbitrary place.

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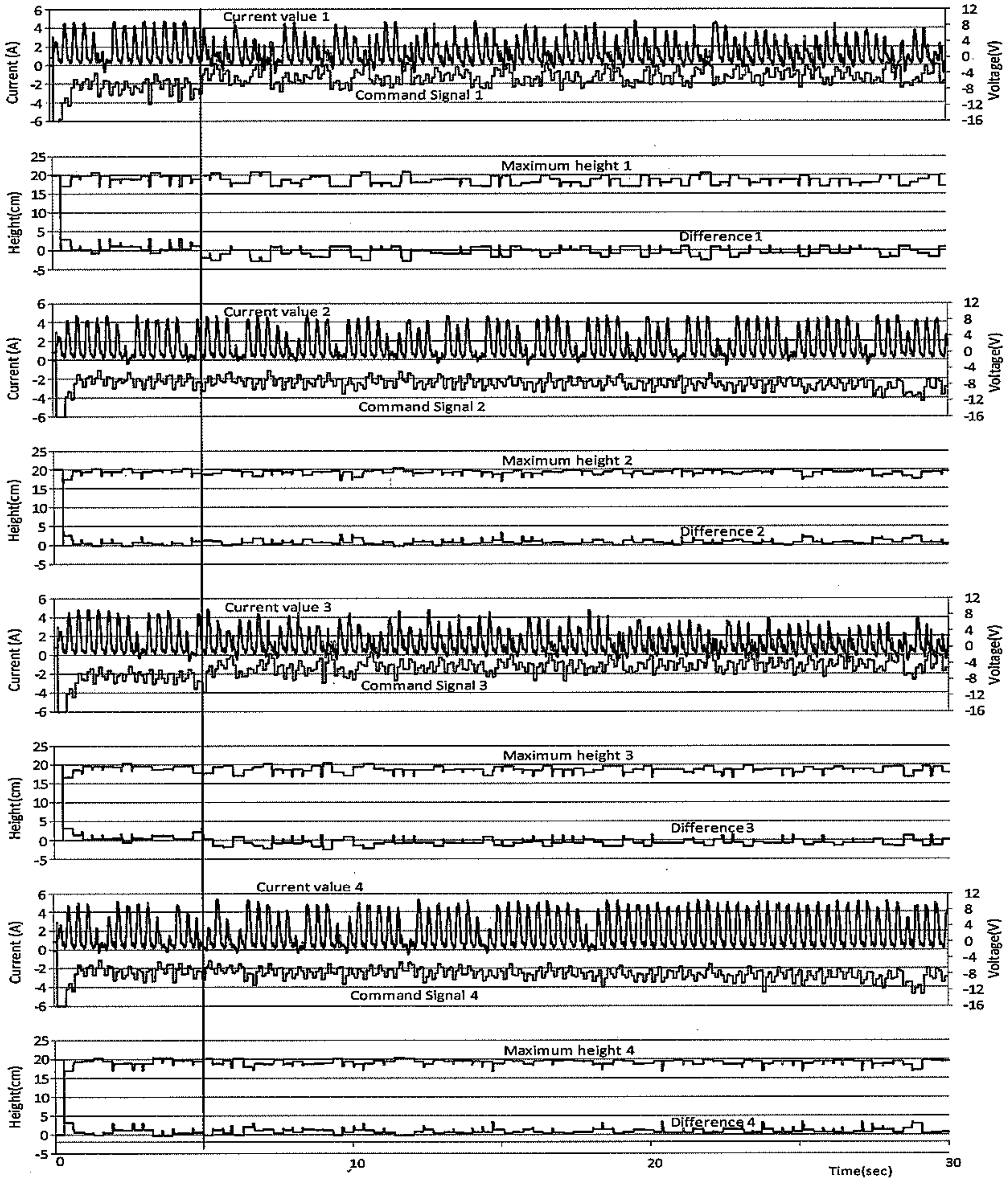

Fig. 7. Experimental results for moving performances in 30sec

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