Effectiveness of Central Pattern Generator Model on Developed One Legged Hopping Robot

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Abstract— **The paper presents the validity of using Central Pattern Generator (CPG) model to develop one leg hopping robot which hops higher and rhythmically. Infrared Ranging (IR) sensor is mounted on a platform to measure the distance of hopping performance. The distances of IR sensor from the platform to the floor in both static and vertical jumping motion are measured. MATLAB & Simulink model including CPG model is designed to evaluate the performance of IR sensor by converting the measurement data from IR sensor from voltage to distance by using function blocks. The result shows that the one leg hopping robot with CPG model is able to achieve maximum hopping height at 4cm.**

Keywords- One leg hopping robot, CPG model, and maximum hopping height

I. INTRODUCTION

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 [1]. CPG is a neural network 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 center 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 [2]. The proactive sensory feedback plays an important role in the shaping and coordination of the neural activity with the mechanical activity. Moreover, 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 [3]. A 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 leads to the construction of useful legged type locomotion..

Legged robots which are capable of dynamic operation and active balance have the potential for similar mobility, efficiency, and dexterity as their biological counterparts. There are only such robots would be able to operate in a much larger range of environments and surface conditions than current wheeled and tracked vehicles. Moreover, similar system design and control advances would benefit applications beyond those requiring traditional locomotion, for example dexterous mechanisms for the inspection of power lines, steel trusses, or pipe systems. Once stable and autonomous legged systems are feasible and affordable, there will be no lack of applications. Unfortunately, it is not yet power-autonomous because of its low power and unprecedented efficiency represents important milestones toward that goal [4].

M.H Raibert who has done research on one legged hopping robot is the main contributor of hopping robot research [5]. A pair of pneumatic actuators is equipped to the leg to exert torque between the leg and the body about to hip. Further research was done by Koditscheck and Buhler by introducing discrete dynamic theory which analyzes the dynamics of a simplified hopping robot which focus only on the vertical movement [6]. Besides that, Tukagoshi et at. has studied on numerical analysis and design for higher jumping rescue robot by using a pneumatic cylinder. The robot's leg was designed in rotor type robot which can be used on flatted smooth surface and overcome the irregular surface [7].

In addition, a CPG model including the motor dynamic characteristic of an actuator for the purpose of implementing generation adaptive gait patterns for a quadruped robot under various environments was introduced by Son et al. After that, the research is continued by Kondo et al. by proposing the CPG network to generate continuous jumping motion patterns in quadruped hopping robot [8, 9].

In this paper, CPG model which act as a command center for the musculoskeletal system and the proposed controller system to generate rhythmical and continuous hopping performances are evaluated. Besides that, maximum height detector system from MATLAB & Simulink is used to measure maximum hopping height of the one legged hopping robot.

II. DEVELOPED HOPPING ROBOT

A. *Robot Construction*

Fig. 1 shows the construction of the developed one legged hopping robot which its overall length and width is 160mm, overall height is 430mm and its weight is 2.5kg. The one legged hopping robot is consisted of a platform which is linked through a linear bushing to support its vertical hopping performance. A DC geared motor (12V, 200min-1, 0.098Nm), a crank and a spring are joined together to form a leg which is attached to the crankshaft.

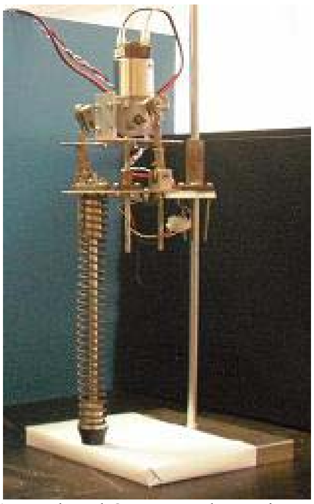

Fig.1 Developed One Legged Hopping Robot

DC geared motor plays as the main role of the one legged hopping robot performance. DC amplifier is used to drive the DC geared motor to provide torque through the crank to push the platform. Fig. 2 presents the principle hopping mechanism of the developed one legged hopping robot. Periodical hopping motion of one legged hopping robot is achieved by converting the periodic force of motor torque to the spring. By applying suitable force at suitable time to the spring, floor repulsive force can be used to generate the continuous hopping motion of the one leg hopping robot.

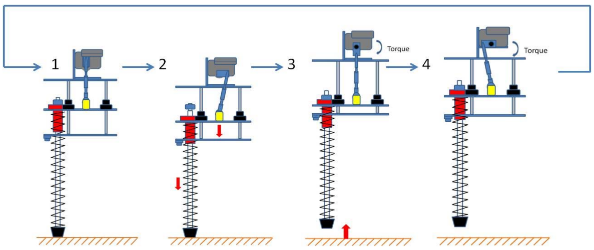

Fig.2 Hopping Mechanism

B. *Experimental Setup*

Fig. 3 shows the experimental setup for development of the one legged hopping robot. The system needs two different computers which are connected through Ethernet to each other. One of the computers is included with MATLAB & Simulink model functions as the host computer while the other one plays as xPC target computer. The model which built by Realtime workshop is downloaded to the xPC target computer and run by using Realtime OS. The measurement of sensor on the leg will be send to the A/D converter and input to the xPC Target Computer which is embedded is the Microbox as the experimental results.

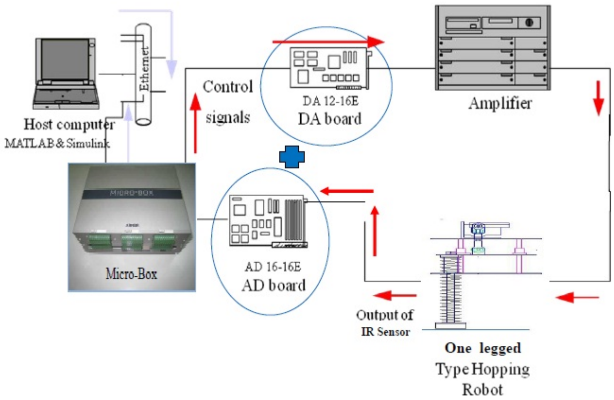

Fig.3 Experimental Setup

III. SYSTEM CONFIGURATION

A. *CPG Model*

Fig. 4 shows the block diagram of the CPG model which is the main part of one legged hopping robot. Mechanical dynamics of the leg is included into the inhibitory unit. Parameters u_e and u_i denotes the internal state of the excitatory unit and inhibitory unit, b and c denotes the intrinsic excitatory and inhibitory coupling parameter, a denotes the excitatory coupling factor while B_o 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 is formulated as

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

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

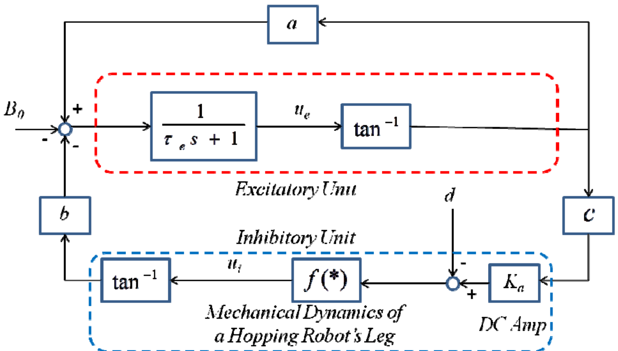

Fig.4 Block Diagram of CPG Model

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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 disturbances which is the floor repulsive force for this case. CPG may change the amplitude and frequency of internal states u_e and u_i by only hanging the coupling parameters a, b, c, time constant τ_e and the mechanical dynamics of the hopping robot arbitrarily.

IV. EXPERIMENTAL RESULT

A. Evaluation on Infrared Ranging Sensor

In the developed one legged hopping robot, IR sensor is used to measure the hopping height because of its efficiency and small size which is fit to the robot size. The experiment is started by measuring the distance from a certain height at static position to the surface manually which is set at 10.2cm from floor. The result of height measurement of one legged hopping robot at static position shows the existence of noise in the measurement data as shown in Fig. 5. This problem is solved by inserting a by-pass capacitor between the power line and ground of the IR sensor to stabilize the power supply line thus reducing the noise which is shown by Fig. 6.

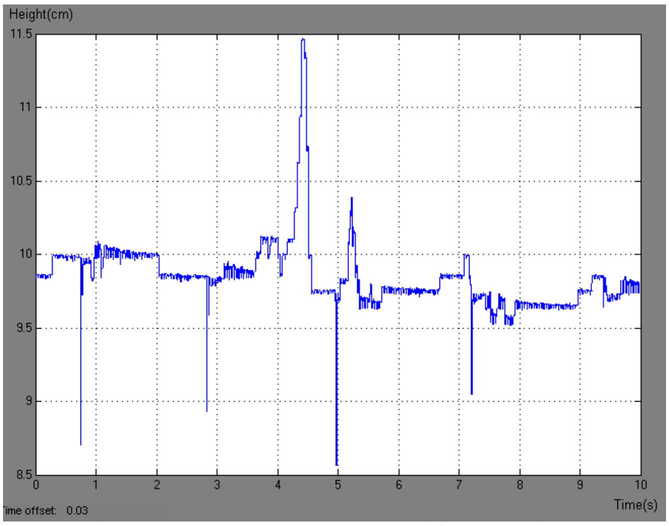

Fig.5 IR sensor Output Measurement without Capacitor

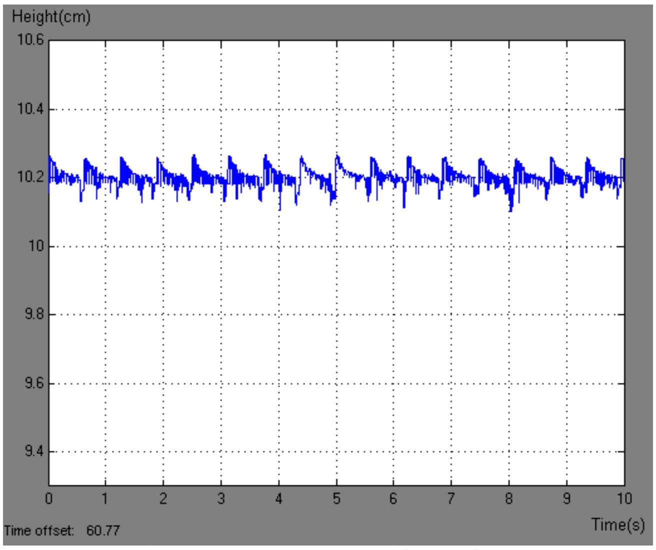

Fig. 6 Output Measurement with Capacitor

The IR sensor block diagram is designed by using MATLAB & Simulink in order to calibrate the IR sensor. The output voltage value can be determined through simulating the Simulink block diagram as the interface of IR sensor to the Microbox. The reading of output voltage values was taken at different height measurement which is increased by 10 cm manually. Characteristic curve of IR sensor is verified by plotting the output voltage value versus distance of the IR sensor to the surface. Another several reading also has been taken to get the average output voltage reading for IR sensor as shown in Table 1.

Table 1 Measurement Data of IR SENSOR Calibration

HEIGHT (CM)	1/HEIGHT (CM^{-1})	OUTPUT VOLTAGE 1 (V_1)	OUTPUT VOLTAGE 2 (V_2)	OUTPUT VOLTAGE 3 (V_3)	AVERAGE OUTPUT VOLTAGE (V)
10	0.1000	2.7830	2.6860	2.6540	2.7070
20	0.5000	1.3690	1.3510	1.3150	1.3450
30	0.0330	0.9311	0.9450	0.9251	0.9337
40	0.0250	0.7206	0.7090	0.7288	0.7195
50	0.0200	0.6719	0.6698	0.6587	0.6668
60	0.0170	0.5329	0.5213	0.5013	0.5185

From the above result, the characteristic of 1/Distance versus Voltage is obtained. The relationship between output voltages of IR sensor and distance can be expressed as conversion formula representing by the below equation where V_{out} is the voltage output from sensor and D is the distance measured from sensor at the platform to the ground.

$$D = \frac{1}{0.0430V_{out} - 0.0129} \quad (1)$$

B. Evaluation on Maximum Hopping Height System

In order to evaluate the hopping performance of CPG model which is included in this developed one legged hopping robot, the experiment of maximum hopping height is done to determine the achievable maximum hopping height of the one legged hopping robot by jumping vertically. The experiment is conducted in two conditions which are without CPG model and with CPG model. Result for experiment of hopping robot without CPG model is shown by Fig. 7 which the maximum vertical jumping height is only 2.98 cm.

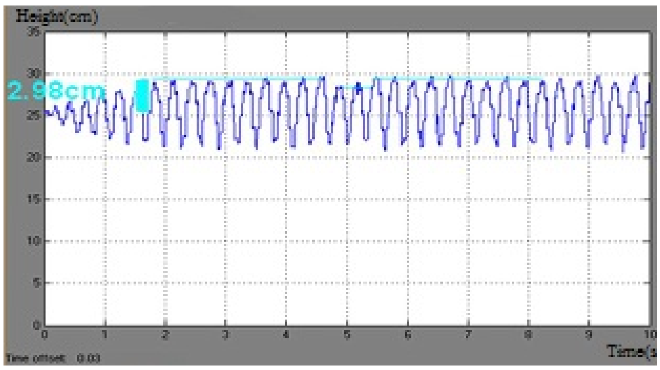

Fig. 7 Experimental result of maximum height without CPG model

On the other side, result for maximum achievable hopping height measurement for one legged hopping robot with CPG model is 4cm which is shown by Fig. 8.

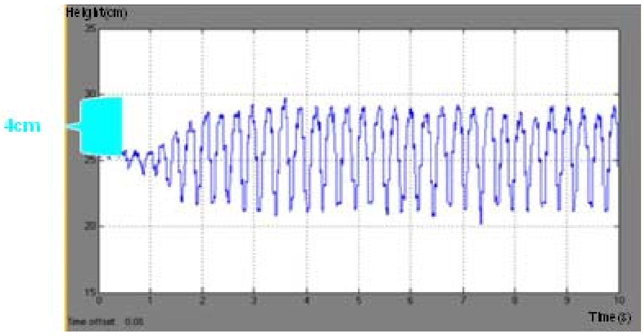

Fig. 8 Experimental result of maximum height with CPG model

Besides that, output distance measurement of IR sensor can be automatically obtained by inserting the output voltage value and the height into the lookup table in Simulink block diagram. The output value displayed in the scope is tally to the value shown by the display block diagram.

CONCLUSIONS

In this paper, CPG model which act as a command center for the musculoskeletal system and the proposed controller system to generate rhythmical and continuous hopping performances are evaluated. Besides that, maximum height detector system from MATLAB & Simulink is used to measure maximum hopping height of the one legged hopping robot.

Study and development of multi-leg hopping robot for better moving motion performance is recommended for future study. In addition, simulation model for the hopping robot is needed in order to identify the ideal parameters for hopping performance in arbitrary place.

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