Central Pattern Generator in Bio-inspired Robot: Simulation using MATLAB

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Abstract

Central pattern generator (CPG) is defined here as a neural network responsible for the production of the timing cues of a rhythmic motor output pattern. In biological system, the CPG is a network of neurons that generate the rhythmic movements such as locomotion of animals. This rhythmic movement will induced a coordination of physical parts that necessary for stable locomotion. To implement this control system and created the locomotion control for bio-inspired robot, we used the neural oscillator to mimic this CPG function. In this paper, Matsuoka's oscillator is been used as neuron model of CPG in order to express the motion of our bio-inspired robot. The outputs of this CPG network are used as the target angles of corresponding joints in this robot. With MATLAB software, we produced the simulation result on the CPG model for the robot. Finally, we hope with this result, we can build the bio-inspired controller based on CPG function for our bio-inspired robot.

Keywords:

Central Pattern Generator (CPG), Matsuoka Oscillator, Extensor Neuron (EN), Flexor Neuron (FN).

Introduction

In 21st century, robots and robotics technologies are expected in a many areas, especially in extreme environments which are too dangerous to access directly by human beings such as underwater environment. It is important for researcher to take a look for the robustness of the robotic system in the motion and the structure which is needed to be strong enough to withstand the disturbance and breakdowns.

Nowadays, many robotic systems that have been developed are inspired from the nature. The goal is to use biological inspiration to engineer machines that emulate the performance of animals, particularly in instances where the animal's performance exceeds current mechanical technology[1]. Copying animals by the bio-inspired approach attempts to seek common solutions from engineering and biology for increased efficiency and specialization in robotic technologies.

As one of method for development of robust robotic system, there is an approach following architecture of biological nervous system. In biological system, the central pattern generator (CPG) is a network of neurons that generate the rhythmic movements such as locomotion of animals. This rhythmic movement will induced a coordination of physical parts that necessary for stable locomotion.

In this paper, we used the neural oscillator to mimic this CPG function in order to express the motion of our bio-inspired robot.

Central Pattern Generator

There are various models of CPG have been developed using neural oscillator, such as Matsuoka Model [3] [4], Terman –Wang Model [5] and so on. The neural oscillators model that represent the function of CPG consists of many set of neurons, and rhythm patterns are generated on each set of neuron by affecting each other.

In this paper, we are using the Matsuoka Oscillator model as the neuron model of neural oscillator. It consists of two simulated neurons; extensor neuron (EN) and flexor neuron (FN) that interconnected in mutually inhibitive network. Figure 1 shows a single neural oscillator interconnected by weights.

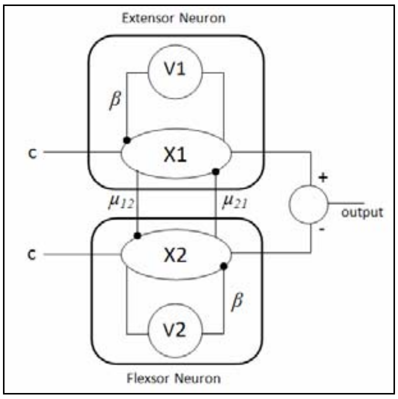

Figure 1 - Matsuoka Oscillator

This model can be expressed in equation (1) - (6), where x_i is the membrane potential of the i-th neuron, v_i is the variable that represents the degree of adaptation, c is the external input with a constant rate, β, τ_u and τ_v are parameters that specify the time constant for the adaptation, and μ_{ij} is the weight between neurons.

$$\tau_u \frac{dx_1}{dt} = -x_1 - \sum h_j g_j - \beta v_1 - \mu_{21} y_2 + c \qquad (1)$$

$$\tau_v \frac{dv_1}{dt} = -v_1 + y_1 \qquad (2)$$

$$\tau_u \frac{dx_2}{dt} = -x_2 - \sum h_j g_j - \beta v_2 - \mu_{12} y_1 + c \qquad (3)$$

$$\tau_v \frac{dv_2}{dt} = -v_2 + y_2 \qquad (4)$$

$$y_i = \max(0, x_i) \qquad (5)$$

$$y_{out} = y_1 - y_2 \qquad (6)$$

The frequency, pattern and amplitude of oscillation of the neurons in a neural oscillator can be changed by varying the parameters of the above equation.

i. External input (c)
The amplitude is positively correlated to the external input c. The inputs to both the neurons in the neural oscillator are same. As the input c is increased a greater rise in x_i is obtained within the same rise time (τ_u). With further increase in the input, x_i continues to increase within same time period as long as the stability criteria given in the last section is satisfied.

ii. Adaptation Firing rate (β)
The frequency is positively correlated to the adaptation firing rate, β. With increase in β, the output x_i, decrease at a faster rate which is proportional to the increase in value of β. Hence the neuron output drops faster and results in increase of frequency.

iii. Rise time and adaptation time (τ_u and τ_v)
Frequency is negatively correlated to the rise time (τ_u) and adaptation time (τ_v). With an increase in rise time the neuron output x_i rises to the same amplitude within the increased time. Similarly x_i drops within increased adaptation time. Both of these changes reduce the frequency of oscillations.

To produce a stable rhythm the rules are as follows [3]:

$$\frac{\mu_{12}}{(1+\beta)} < 1 \, and \, \frac{\mu_{21}}{(1+\beta)} < 1 \qquad (7)$$

$$\sqrt{\mu_{12} * \mu_{21}} > 1 + (\tau_u / \tau_v) \qquad (8)$$

Simulation

In this paper, we are constructed a CPG network to simulate the undulatory locomotion in animal such as snake. Using 10 sets of neural oscillators, based on our bio-inspired robot that has 10 joints, each set are interconnected to each other. Extensor neurons are connected to flexor neurons of the neighbor neural oscillator, and flexor neurons are connected to extensor neurons of the neighbor neural oscillator. Figure 2 shows the architecture of 10 sets of neural oscillator.

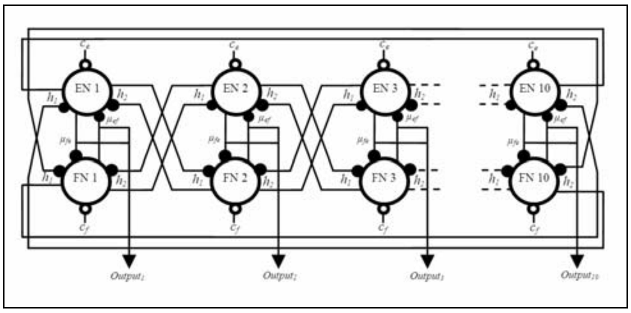

Figure 2 - The architecture of CPG network

The simulation of this CPG network are been done using MATLAB software. With Simulink, we are able to build the single neural oscillator based on the CPG's equation (1) - (6) and also constructed a CPG network for the simulation. Figure 3 shows the single neural oscillator and figure 4 shows the CPG network using MATLAB. The network architecture is designed to have closed loop to generate periodical successive signals with a certain phase.

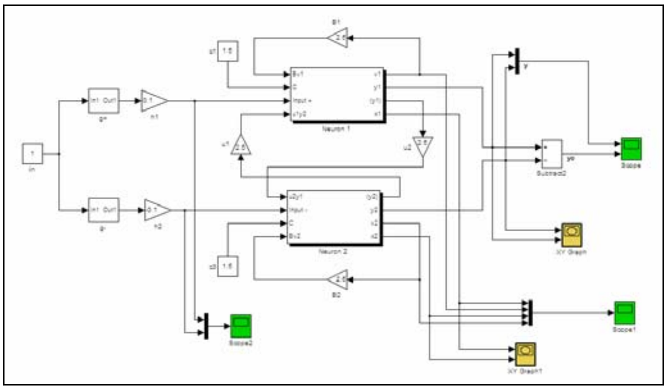
Figure 3 – Single neural oscillator using MATLAB

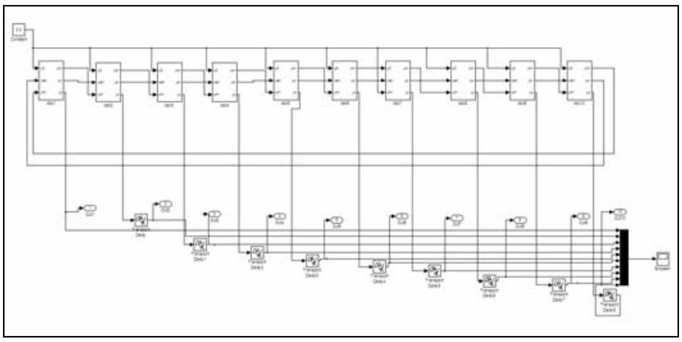
Figure 4 – CPG network using MATLAB

The simulation of body mechanics for this bio-inpired robot is modeled using the SimMechanics toolbox in Simulink. It provides so-called "physical modeling" blocks to represent physical components and their geometric and kinematic relationships directly. This connection is shown in Figure 5.

To obtain the lateral undulatory mode, characterized by a lateral S-shaped wave travelling from head to tail, the output that have been obtained from CPG network as shown in Figure 4, is connected to the joint angle that have been build in Figure 5.

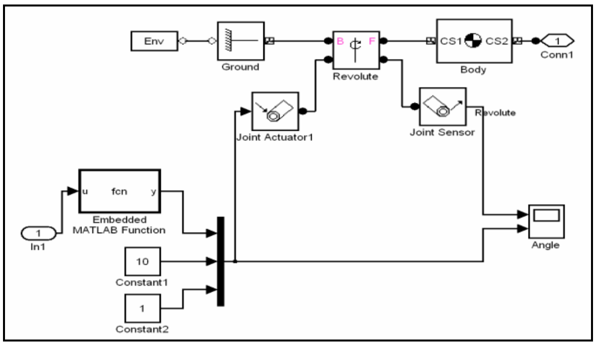

Figure 5 - The internal structure of body segment

Snakes move using friction between the ground and their bodies and propagating body waves, which have a certain phase difference for each motion pattern. Thus, the delay blocks were used between the oscillators to achieve this motion pattern. This connection is shown in Figure 6.

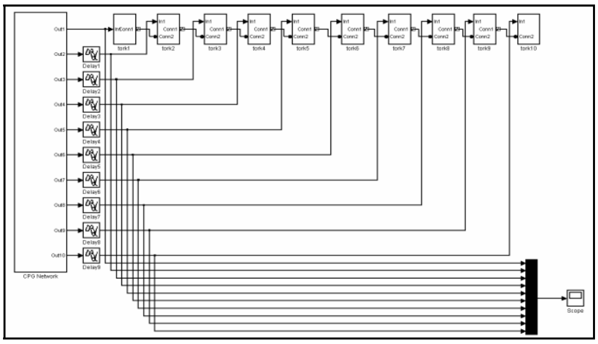

Figure 6 – The mechanical body simulation using SimMechanics

Calculation between phase angle φ in radians (rad), the time delay Δt, and the frequency f is:

Phase angle

$$\varphi = \omega \cdot \Delta\tau = 2\pi \cdot f \cdot \Delta\tau \qquad (9)$$

According to the simulation result for Matsuoka oscillator in Figure 7, taking the frequency obtained is 0.4545Hz and by referring to equation (9), the time delay needed in between the oscillations is 0.22 seconds.

Results

We are carried out the simulation using a set of CPG parameters as shown in Table 1. Those parameters are enter on each set of neural oscillator as shown in Figure 3 and 4, and give the output as shown in Figure 7 and Figure 8.

Symbol	Quantity
β	2.5
$c_e = c_f = c$	0.4
μ	1.5
$h1$	0.1
$h2$	0
$f_i^e = f_i^f$	0
τ_u	0.25
τ_v	0.5

Table 1 - The parameter for the CPG network

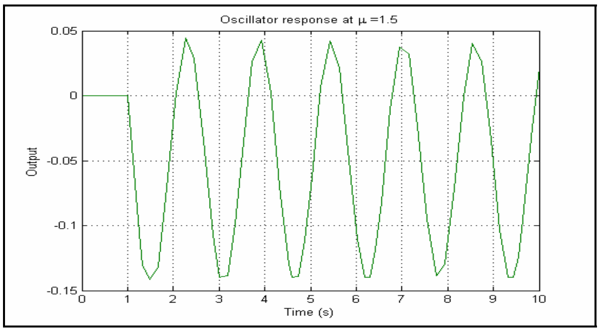

Figure 7 – The ouput for single neural oscillator

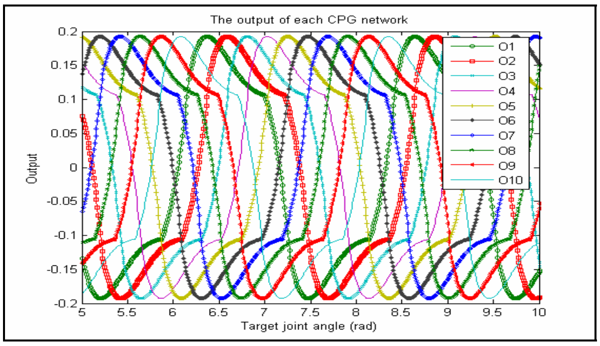

Figure 8 - The output of each CPG network

The bio-inspired robot can change heading using rotation by only changing the parameter c_e and c_f. In this simulation, when the parameter c_e and c_f are set to 0.8 and 0.4 for rightward, neural oscillator's wave shifts as shown in Figure 9. Figure 9 is shown only neural oscillator output1 for facilitating visualization. When c_e and c_f are set to 0.4 and 0.8, neural oscillator wave shift as shown in Figure 10.

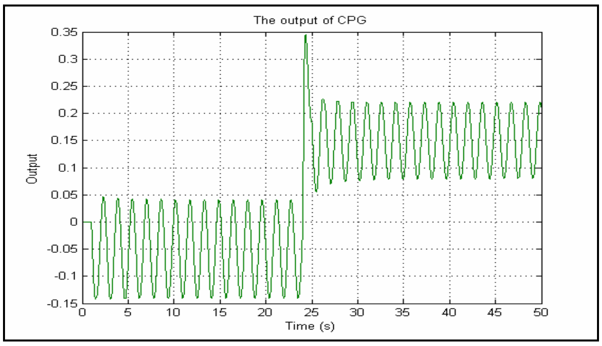

Figure 9 - The output of CPG network in right turn motion on MATLAB simulation

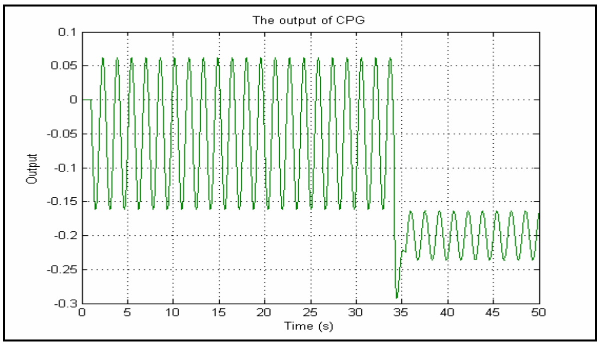

Figure 10 - The output of CPG network in right turn motion on MATLAB simulation

The overall mechanical simulation of the bio-inspired robot for 10s using CPG network is shown in Figure 11.

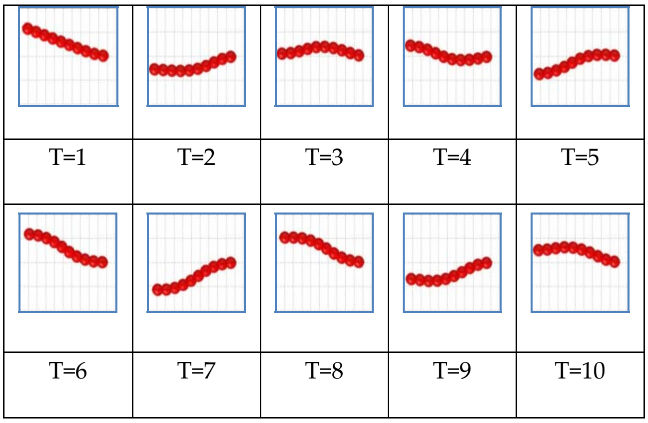

Figure 11 - The overall body shape simulation

Conclusion

It is now clearly understood that CPG is responsible for rhythm generation in locomotion action in animals. The basic components of the CPG used in the project are Matsuoka oscillator. These oscillators consist of two neurons with self adaptation effect and interconnected via inhibitive connections.

With this CPG network, we can control for 10 joints based on our bio-inspired robot design. Moreover, we also can control the heading of the robot by changing the parameter of the CPG network. Based on this simulation result, we are planning to build the bio-inspired controller based on CPG function for our bio-inspired robot.

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