Locomotion Control of a Serpentine Crawling Robot Inspired by Central Pattern Generators

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***Abstract*—Serpentine locomotion is highly coordinating and full of adaptive ability in a clutter environment. Such outstanding and unique characteristics are acquired through millions of years' evolution. It is highly desirable to enhance robot with such characteristics, which is one of the ultimate aims of biomimetic research. To achieve this goal, we adopt a central pattern generator (CPG) inspired controller to generate Serpentine locomotion in a crawling robot. According to biology studies, CPGs are a set of neuronal circuits, which are responsible for producing rhythmic motion employed in animal locomotion. Such locomotion generation approach makes use of a set of coupled Kuramoto Oscillators to imitate of CPG in a nerve system. Moreover, to deal with dynamically changing environments, a feedback based on fuzzy logic control strategy is investigated. Finally, the proposed control approach is verified through the experiments of a crawling robot prototype.**

I. Introduction

Over billions of years, snakes have developed extraordinary skill of locomotion which have been shaped by nature selective pressures. Owing to their environmental adaptability, snakes are able to survive in various environments, such as mountain, sea, grassland, jungle and desert. Hence, the astonishing motor ability of snakes has inspired scientists to develop a new kind of ground robot whose structures are intimated from snake morphology.

From the viewpoint of bio-robotics, Figuring out how snakes move and further biological knowledge can be applied to designing of snake robots is significant. In nature, the locomotion of snakes can be classified in four modes: Serpentine locomotion, Rectilinear locomotion, Concertina locomotion and Side-Winding locomotion [1]. In these locomotion modes, Serpentine locomotion, with the feature that each part of the body leaves similar tracks, can be found in almost all kinds of snakes. To transplant this kind of locomotion from snakes to robots, so far, two methods have been adopted, namely, model-based and bio-inspired. The model-based method applies discrete mechanical multi-link movements of a robot to match the biological Serpentine curve. Many crawling robots generate Serpentine locomotion in this manner, notable examples include the work reported in [2][3][4]. However, the model-based approach involves a complicated model with numerous calculations which greatly hinders the approach from real-time application.

From neurobiology studies, it has been generally accepted that the movement of vertebrates such as flying, swimming and walking, can be generated based on Central Pattern Generators (CPGs). Therefore, recently, researchers started to pay more attention to the bio-inspired control method in the development of biomimetic crawling robots. Many studies aim to generate Serpentine locomotion in robots via artificial CPGs in the past decades, such as the works in [5][6][7]. Most of these studies focus on robotic CPG-based locomotion generation, but few of them consider the locomotion tuning with the interaction between the robots and the environment. However, for a more intelligent need in many case to deal with dynamically changing environments, a more suitable degree of locomotion adaptability is gradually needed. Biological evidences have proven that biological locomotion adaptation can be achieved through the commanding signals from higher levels in the nervous system. In robotics, several preliminary studies intimate this biological locomotion control mechanism to develop a data-driven controller to tuning the locomotion of the biomimetic robots. For example, [8] proposed an iterative feedback tuning based-PID controller to tuning the locomotion generator of a robotic fish. In [9], a fuzzy logic controller is employed to enhance the adaptability of a hexapod robot locomotion.

The aim of this work is to develop an adaptive CPG-based locomotion controller for a Serpentine crawling robot. This system adopts an artificial CPG network to generate the Serpentine locomotion. Even through the CPG-based locomotion is easy to be online tuned, the tuning principle is hard to know due to a mass of uncertain variables of modelling which influence the interaction between the robot and the environment. To minimise the effect of system uncertainties and simplify the parameter tuning process, a Fuzzy logic Controller (FLC) is adopted to develop an adaptive locomotion control of the crawling robot platform.

The rest of the paper is organized as follows. Section 2 presents the crawling robot prototype developed in this work. Serpentine locomotion generator in the robot via an artificial CPG network is detailed in Section 3. Section 4 explores the adaptive locomotion control strategy with a trajectory tracking experiment. Finally, Section 5 concludes this paper.

II. Design of a crawling robot

In nature, snakes' body are covered with muscles which can stretch or shrink coordinately to play the role of actuators and generate thrust in accordance with the interaction principle between the body movements and the ground surface. As shown in Fig.1, from engineering perspective, a snake can be

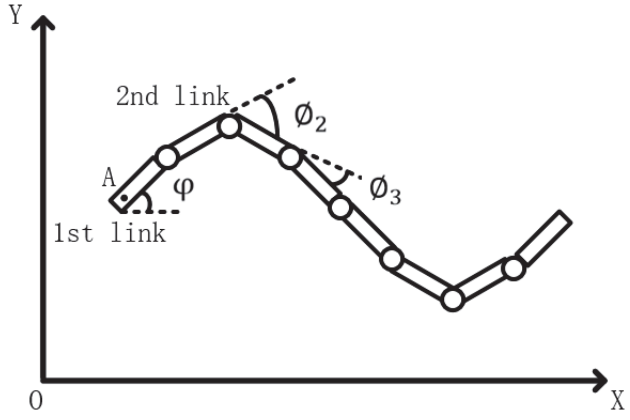

Fig. 1. Joint-link skeleton model of crawling robot.

modelled as a joint-link skeleton model and servo motors can play similar roles as muscles. The position and orientation of the skeleton model is described by three coordinates, namely, X, Y and ϕ. X and Y indicate the position of the point A in the one-fourth of the first link length, while ϕ denotes the angle between X axis and the orientation of first link. The movement of the robot in the world coordinate system is described as $f(X,Y,\phi,t)$. ϕ_i denotes the actual control angles which are joint angles between neighboring links ($i = 1,2,...,n$). In this work, $n = 7$.

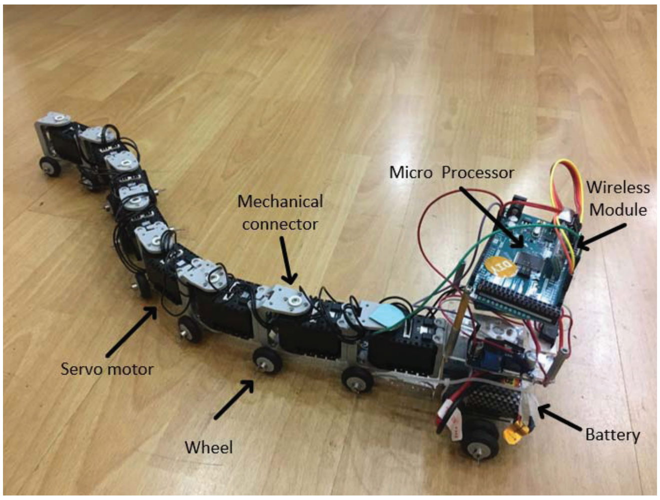

Fig. 2. The prototype of crawling robot.

Based on the joint-link model, a crawling robot is developed as shown in Fig.2. The length of the crawling robot is approximately 60cm. Although natural snakes have thousands of links along their bodies, to simplify the implementation, our robotic snake has equipped with only 8 links. Each link connects with the next through a servo motor (Dynamics AX-12). A compartment which contains a micro controller board (ATmega2560 32 micro processor), a wireless module (Bluetooth) and a Li-Po battery is located at the front of the robot. The micro controller is responsible for controlling all servo motors, receiving and processing sensor feedback signals via the wireless module, and making control decisions. Moreover, a pair of passive wheels are mounted under each link to provide asymmetric friction to facilitate locomotion on flat surfaces.

III. Generation Serpentine locomotion

A. CPG model

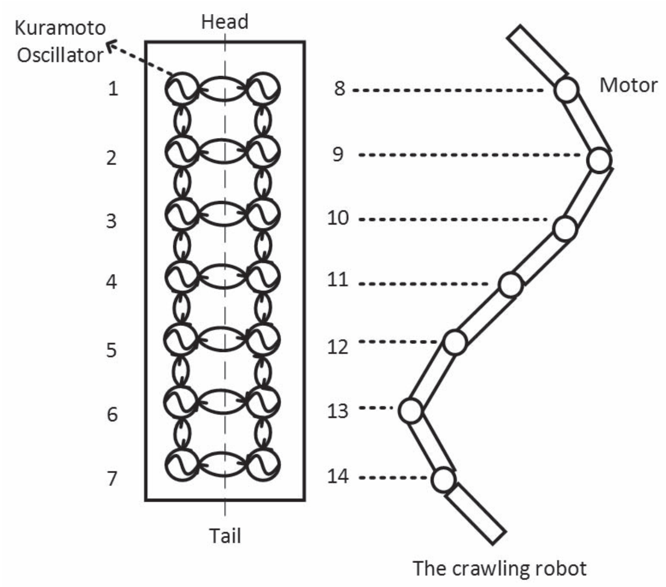

Fig. 3. The structure of the CPG model.

In this paper, as illustrated in Fig.3, a CPG model originally proposed in [10] is adopted. The model is a double chain of Kuramoto oscillators with nearest neighbor coupling. The total number of oscillators can be computed as $2 \times n$. The CPG associated with coupled oscillators is implemented as the follows:

$$\begin{cases} \dot{\theta_k} = \omega_k + \sum\limits_{j \varepsilon T(k)} w_{kj} sin(\theta_j - \theta_k - \psi_{kj}) \\ \ddot{r_k} = a_k(a_k/4(R - r_k) - \dot{r_k}) \\ x_k = r_k(1 + cos(\theta_k)) \end{cases} , \quad (1)$$

where, θ_k and r_k indicate the phase and the amplitude of the kth oscillator, ω_k and R_k determine the intrinsic frequency and amplitude, a_k is a positive constant influences the transient time when R_k changes. The coupled between the oscillators is defined by the phase bias ψ_{kj} and the weight w_{kj} influences the transient time when ψ_{kj} changes. In addition, according to the topology shown in Fig.3, an oscillator k receives inbound couplings from the oscillators in the discrete set $T(k)$.

Thus, based on the structure of the CPG network, each output of the joint (servo motor joint angle) can be determined by the outputs of the two oscillators:

$$\phi_i = x_i - x_{i+7}. \quad (2)$$