Chapter XII
A General Rhythmic Pattern Generation Architecture for Legged Locomotion

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ABSTRACT

As an engine of almost all life phenomena, the motor information generated by the central nervous system (CNS) plays a critical role in the activities of all animals. After a brief review of some recent research results on locomotor central pattern generators (CPG), which is a concrete branch of studies on the CNS generating rhythmic patterns, this chapter presents a novel, macroscopic and model-independent approach to the retrieval of different patterns of coupled neural oscillations observed in biological CPGs during the control of legged locomotion. Based on scheduling by multiple edge reversal (SMER), a simple and discrete distributed synchroniser, various types of oscillatory building blocks (OBB) can be reconfigured for the production of complicated rhythmic patterns and a methodology is provided for the construction of a target artificial CPG architecture behaving as a SMER-like asymmetric Hopfield neural networks.

INTRODUCTION

Animal gait analysis is an ancient science. As early as two thousand years ago, Aristotle described the walk of a horse in his treatise (Peek & Forster, 1936) *De Incessu Animalium*: "The back legs move diagonally in relation to the front legs; for after the right fore leg animals move the left hind leg, then the left fore leg, and after it the right hind leg." However, he erroneously believes that the bound gait is impossible: "If they moved the fore legs at the same time and first, their progression would be interrupted or they would even stumble forward… For this reason, then, animals do not move separately with their front and back legs."

Following the legend, modern gait analysis also originated with a horse, namely, a bet concerning the animal's gait (Taft, 1955). In the 1870s, Leland Stanford, the former governor of the state of California, became involved in an argument with Frederick MacCrellish over the placement of the feet of a trotting horse. Stanford put 25,000 dollars behind his belief that at times during the trot, a horse had all of its feet off the ground. To settle the wager, a local photographer, Eadweard Muybridge, was asked to photograph the different phases of the gaits of a horse. As a matter of fact, Stanford was correct in his bold assertion.

Aristotle and Stanford's insights into horse gaits can be viewed as the classical representations of embryonic ideas which lead to the modern studies of rhythmic pattern formation. After the case of Stanford there followed about eighty years of silent time till the 1950s, when A. M. Turing (1952) analysed rings of cells as models of morphogenesis and proposed that isolated rings could account for the tentacles of hydra and whorls of leaves of certain plants. Meanwhile, A. L. Hodgkin and A. F. Huxley published their influential paper (1952) on circuit and mathematical models of the surface membrane potential and current of a giant nerve fibre. The history has never seen such a prosperous era in the development of science and technology during the recent fifty years. With the rapid development of computational methods and computer techniques, many great scientific interdisciplines such as neural networks have been born and grew astonishingly. Obviously, it is not exaggerative at all to say that Turing et al.'s pioneer works on pattern formation are the cradle of modern connectionism. It is also interesting to notice that the macro- and microscopic approaches have coexisted since the initial stage of the modern biological rhythmic pattern research, just as the two examples stated above.

Rhythmic Patterns in Artificial Neural Networks

It is widely believed that animal locomotion is generated and controlled, in part by central pattern generators (CPG), which are networks of neurons in the central nervous system (CNS) capable of producing the rhythmic outputs. Current neurophysiological techniques are unable to isolate such circuits from the intricate neural connections of complex animals, but the indirect experimental evidence for their existence is strong (Grillner, 1975, 1985; Stein, 1978; Pearson, 1993).

The locomotion patterns are the outputs of musculoskeletal systems driven by CPGs. The study of CPGs is an interdisciplinary branch of neural computing which involves mathematics, biology, neurophysiology and computer science. Although the CNS mechanism underlying CPGs is not quite clear to date, artificial neural networks (ANN) have been widely applied to map the possible functional organisation of the CPGs network into the muscular motor system for driving locomotion.

The constituents of the locomotory motor system are traditionally modelled by nonlinear coupled oscillators, representing the activation of flexor muscles and the activation of extensor muscles by, respectively, two neurophysiologically simplified motor neurons. Different types of neuro-oscillators can be chosen and organised in a designed coupled mode, and usually with appropriate topological shape to allow simulating the locomotion of relative animals (Bay & Hemami, 1987; Linkens et al., 1976; Tsutsumi & Matsumoto, 1984). All internal parameters and weights of coupled synaptic connections of the oscillator network are controlled by the environmental stimulations, CNS instructions and the network itself. The nature of the parallel and distributed processing (PDP) is the most prominent characteristic of this oscillatory circuit that can be canonically described by a group of ordinary

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