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Short Communication

Biologically inspired spiking neural network for autonomous locomotion control of snake-like robots

Abstract

In this paper, we proposed a bio-inspired hierarchical control architecture for the autonomous locomotion control of snake-like robots. Mimicking the central nervous system of animals, the spiking neural network and the central pattern generator-based controller are utilized to make high-level decision and generate medium-level locomotion control signals, respectively. The low-level control of the actuators is accomplished by local PID controllers. We present a convert method to obtain the spiking neural network from a conventional neural network. The case study results demonstrate the effectiveness of proposed architecture.

Keywords: bio-inspired robots, neutral networks, autonomous locomotion

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Abbreviations: SNN, spiking neural network; CPG, central pattern generator; DOF, degree of freedom

Introduction

Snake-like robots have been widely studied due to their special 3D locomotion ability and the adaptability in diverse complex environments. Autonomous locomotion, that is, acquiring environment information, making locomotion decisions independently and then performing locomotion, is of the essence for snake-like robots to complete self-governed tasks in various complex terrain. The traditional model-based control methods, including numerical, kinematic and geometric, however, cannot completely meet the challenges posed by dynamic and changing conditions, which has higher requirements on stability and adaptability. Moreover, the high degree of freedom (DOF) of snake-like robots also makes the process of analyzing the state of the robot in real-time difficult. The autonomous locomotion problem is becoming an area in which biology and robotics should closely interact.[1]

Methods

In this paper, we propose a bio-inspired hierarchical control architecture (Figure 1) for the autonomous locomotion of snake-like robots. The architecture mimics the structural principles at work in the locomotion of living creatures. Studies have shown that the locomotion of animals is hierarchically controlled by the central nervous system, which is mainly composed by the following organs that perform functions in different levels.

i. The cerebral cortex, which plays a key role in high-level functions such as perception, awareness, thought, etc.

ii. The brainstem, which has many basic functions including regulating central nervous system, heart rate, breathing, sleeping, etc.

iii. The spinal cord, which is mainly responsible for coordinating certain reflexes and transferring information between the brain and the rest of the body.

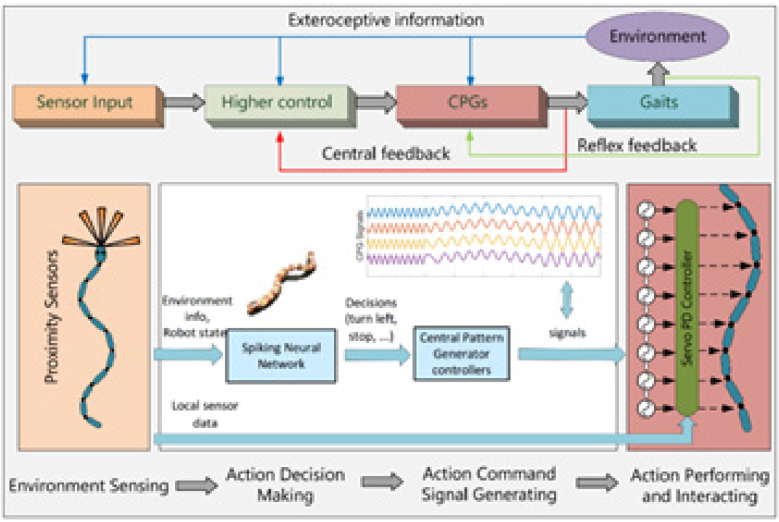

Figure 1 The Spiking Neural Network based hierarchical control architecture.

The proposed architecture is bio-inspired and has similar hierarchical structure to accomplish the perception-action closed loops between the environment and the snake-like robots. It owns the spiking neural network (SNN), the central pattern generators (CPG)-based controllers, local controllers (substrate e.g. biologically the spinal cord).

i. The spiking neural network mimics the cerebral cortex in creatures. It has learning ability and serves as the 'brain' of the robot. SNN is the third generation of neural network model and achieve more realism in a neural simulation.[2] It perceives the environment information and state of the robot via the sensors, and then makes high-level decisions about robot locomotion. The SNN is implemented in three steps (Figure 2). First, run the robot in a target scenario with a self-defined controller that generates locomotion decisions. As a consequence, a dataset containing the sensor data and locomotion actions can be obtained. Second, use the dataset to train a conventional neural network by considering the locomotion action as a classification problem. Finally, transfer the weights to a spiking neural network using Integrate-and-Fire neurons that matches the previous networks architecture.[3]

ii. The CPG-based controller plays a key role in generating command signals for lower level actuators, e.g., servos in each joints of the snake-like robot. Central pattern generators, which are biological neutral networks that produce rhythmic patterned outputs,[4] have been found in all vertebrate species investigated.[5] As a class of bioinspired neural network, CPG is the ideal candidate for practical solution of locomotion control of snake-like robots since its rhythmic patterned output perfectly matches the serpenoid curves-based controlling method of snake-like robots. Moreover, the various gaits of snakes can be generated by the same network without the precise knowledge of system mechanical properties.

iii. Local controllers control actuators (servos in each joint under PID controllers) and sensors (vision, IMU, angle sensors) to interact with the environment, i.e., locomoting in and perceiving the environment, and close the perception-action loops.

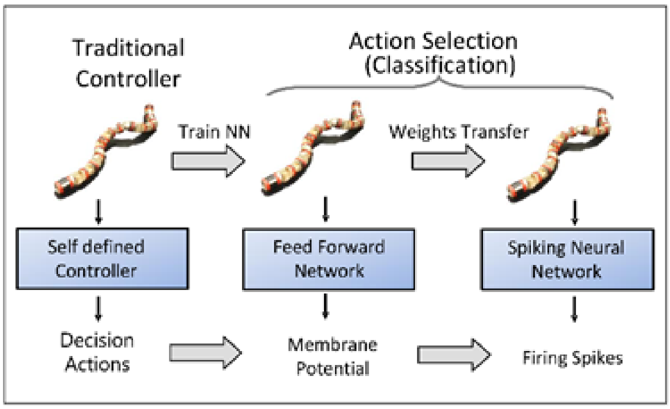

Figure 2 Steps to train the spiking neural network.

Results of case study

The simulated autonomous locomotion scenario consists of enclosures with straight lane, normal corners, and sharp left and right corners as shown in Figure 4. Five distance sensors are placed evenly in the front of the snake-like robot head. We design five locomotion actions for the robot, namely, forward, left, right, hard left, and hard right. The snake-like robot is initially placed on the straight lane for an easy start, since the initial decision for the robot is moving forward. The trajectory of the robot with the SNN-based control architecture is plotted in Figure 4. Observe that the robot generates smooth trajectory in the scenarios of forward, left and right actions. For the hard left and hard right action cases, several fluctuations appears but no collision with the wall happens. Figure 5 displays the confusion matrix of the training algorithm. The matrix shows that the overall accuracy is no less than 95%. In summary, the simulation results demonstrate the effectiveness of the proposed SNN-based hierarchical control architecture.

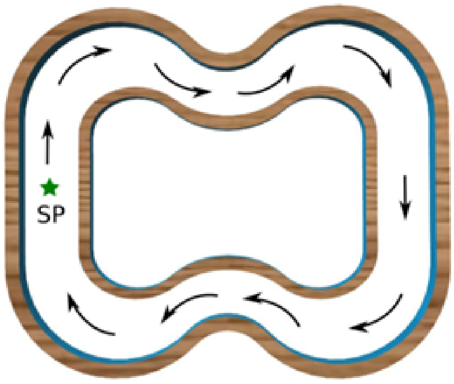

Figure 3 The locomotion environment in the simulation. SP denotes the start point of the snake-like robot.

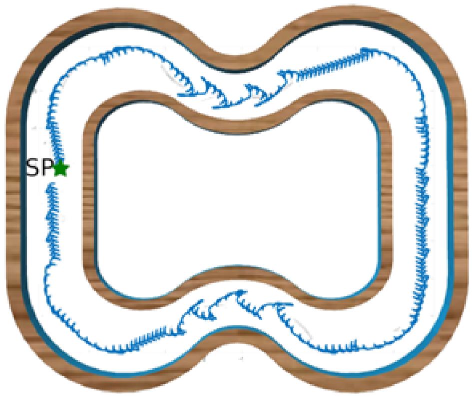

Figure 4 The trajectory of the snake-like robot controlled by the SNN-based hierarchical architecture.

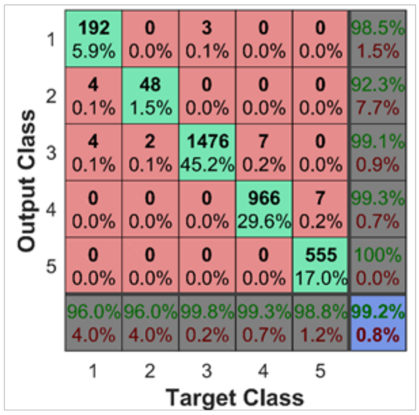

Figure 5 The confusion matrix of the training algorithm. Classes indexed from 1 to 5 denote the five actions.

Conclusion

Inspired by living creatures, we proposed a spiking neutral network (SNN)-based hierarchical control architecture for the autonomous locomotion of snake-like robots. Simulation results demonstrate the effectiveness of the SNN in decision making. How to train the SNN quickly for various environments? How to apply data fusion techniques to the data from various types of sensors for decision making? More interesting issues are still open and deserve further research.

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Conflict of interest

The author declares no conflict of interest.

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