Neuromorphic Control of Quadrupedal Robots

A summer 2023 undergraduate research project to develop a robotic platform for the study and education of robotic locomotion based on event-based and neuromorphic control principles.

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Overview

A Central Pattern Generator (CPG) is a specialized neural network found in the spinal cord or brainstem of the nervous system. Its primary function is to generate rhythmic motor actions such as walking, swimming, or flying autonomously, without the need for continuous input from the brain. CPGs play a pivotal role in regulating repetitive and rhythmic locomotion in animals, and they possess the remarkable ability to swiftly reestablish their oscillatory patterns even in the presence of disturbances or deviations.

Traditionally, achieving rhythmic locomotion in robots, particularly in challenging environments like water bodies, has been a complex task. However, drawing inspiration from principles in neuroscience offers a promising solution, as proven by Salamandra Robotica II, an amphibious robot with salamander-like locomotion developed in EPFL's Biorobotics Laboratory.

In this regard, the aim of this project was to provide researchers and students at CUED with a rapid-prototyping pipeline for designing and testing event-based and neuromorphic control algorithms for locomotion. With the generous support of MathWorks in terms of technical assistance and funding, VEX hardware was obtained, transformed into functional robots, and operated through Simulink-derived neuromorphic oscillators, making use of Simulink's VEX V5 code generation support packages.

Results

Desired Outcomes	*Outcomes Delivered*
A single quadrupedal robot to serve as a platform for rapid deployment of neuromorphic control paradigms.	Two quadrupedal robots with distinct mechanics and gaiting patterns, allowing for more flexibility in investigations.
A collection of Simulink neurons to that can be easily adapted into different neuronal circuits.	A collection of Simulink neurons, simple Central Pattern Generator circuits, and exemplar oscillators and gaits were delivered.
Information regarding how to optimise MQIF Neuron behaviour to achieve a desired gait.	A collection of MATLAB scripts for characterizing neural output in relation to governing parameters, aiding future developers in their investigations.

Future Work

- The Simulink Neurons have been intentionally decelerated by a factor of 4. This adjustment was necessary because the unaltered-speed neurons are only mathematically solvable and stable with a fixed time-step of 1e-4, while the VEX Brain can only accommodate a sampling time of 1e-3. Consequently, their responsiveness may prove insufficient for more complex network designs. Therefore, it is advisable to explore approaches to either address the VEX Brain's sampling time limitation or enhance the solvability of the neurons at slower time-steps.

- Additional exploration is warranted to optimize motor control using CPG waveforms. Currently, the interface relies on a PID controller. The spike trains undergo double integration, resulting in a "position" waveform. This waveform serves as both an input to the PID block and as feedback to modulate the sinusoidal patterns by exciting or inhibiting the core neurons. Ideally, an improved control approach would entail directly inputting the spike train into the motors, complemented using position encoders to correct deviations through excitatory and inhibitory feedback mechanisms.