Biomorphic control for high-speed robotic applications

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Introduction/Motivation

Embodiment is often perceived as one of the key features of biological cognitive systems and has therefore been subject to increasing interest within the neuroscientific community [1][2]. Following this endeavor, the field of neurorobotics has evolved a multitude of different strategies for linking simulations of biologically inspired neural networks to either real-world robots [3] or virtual agents in simulated environments [4]. The complexity of these approaches is however often limited by the available compute resources for either the network simulation – especially in the case of latency-restricted interactions with real-world actuators – or for environmental simulations with rich physical dynamics.

In this work, we present a hardware framework for connecting the accelerated neuromorphic BrainScaleS-2 platform to real-world sensors and actuators and propose an application that utilizes the system’s properties for controlling the coils of brushless electric motors with microsecond-precision. The presented setup will enable research in the field of biologically plausible spiking neural networks in interaction with fast physical processes.

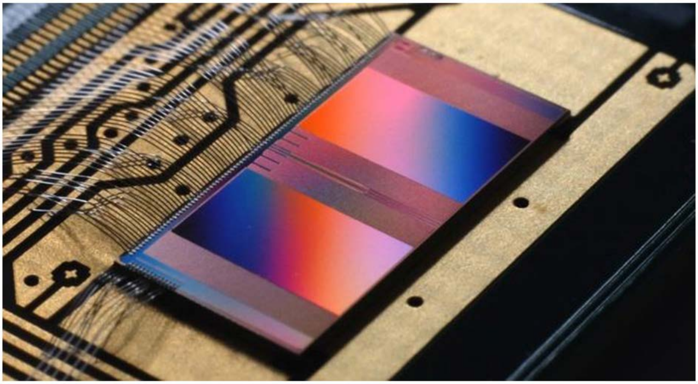

FIGURE 1

Photograph of the 65nm BrainScaleS-2 neuromorphic ASIC. It features 512 AdEx neurons, 612x512 plastic synapses and two embedded SIMD processors for implementing arbitrary on-chip plasticity rules.

Methods

BrainScaleS-2 [5][6] is an established neuromorphic platform based on the likewise named mixed-signal ASIC (**Figure 1**). It features 512 analog neuron circuits that implement the Adaptive-Exponential Leaky-Integrate-and-Fire model [7]. Each neuron receives synaptic input from 256 plastic synapses with a digitally controlled weight of 6bit precision and integrated correlation sensors for STDP-type learning rules. Amongst other observables, the accumulated correlations can be digitized by highly parallel on-chip ADCs and used within two embedded SIMD processors for calculating freely programmable plasticity rules. The analog circuits of BrainScaleS-2 run in continuous time, their time constants are accelerated 1000-fold compared to biology. This speedup factor makes BrainScaleS-2 predestined for ultra-fast robotic tasks that require control loops far beyond biological reaction times.

In addition to the ASIC, each BrainScaleS-2 system contains an FPGA used for stimulating the analog accelerator, recording responses and connecting it to external compute clusters. For the presented robotic hardware framework, we implement a low-latency link for event data from external sensors (sensor

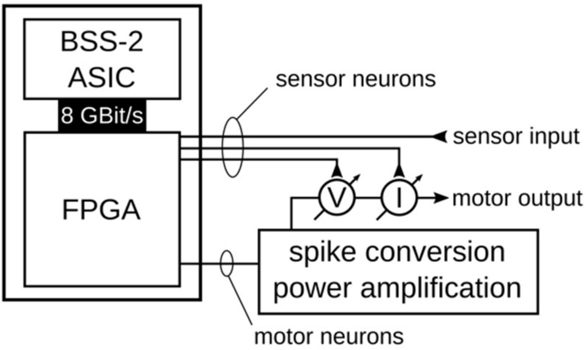

FIGURE 2
Overview on the presented hardware framework for high-speed robotics. Sensory spikes are sent to the ASIC via an FPGA and processed by the analog neural network. Motoric events are processed vice versa.

neurons) and to actuators (motor neurons) in this FPGA (Figure 2). Outgoing and incoming spike traffic is channeled through separate serial links, which – at the cost of serialization latency – allow for runtime-configurable virtual spike channels without excessive hardware requirements for a parallel connection. We separate incoming and outgoing spike traffic in separate physical links to enable the use of different hardware modules for sensory spike sources and motoric spike sinks.

Results and discussion

The presented hardware framework for connecting the BrainScaleS-2 system to external spike-based sensors and actuators has been implemented and tested in an experimental setup. With a serial clock of 16MHz and 256 virtual input- and output channels, we measure a serialization latency of 640ns. Adding the latency between ASIC and FPGA, we measure a total neuron-to-output latency of 1.2us – one order of magnitude faster than typical membrane dynamics on BrainScaleS-2. If less external spike channels are required, the serialization latency is reduced accordingly.

Using this framework, we present an initial biomorphic control circuit for high-speed robotics: Interpreting the coils and magnets of a conventional, fast-rotating brushless electric motor as muscular actors, we have implemented the prototype of a spike-base controller for generating the required rotating electric field. We envision this setup as a versatile platform for the development of biologically plausible learning in spike-based robotic systems. The 1000-fold acceleration factor will allow for greatly reduced training time and thereby facilitate robotic experiments with spiking neural networks of beyond-state-of-the-art size and complexity.

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