Bio-inspired optic flow detection using neuromorphic hardware

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Dynamic Vision Sensor

The DVS\textsuperscript{1} is an event-based vision sensor. Each of its pixels monitors its local brightness level $X(t)$ autonomously and asynchronously emits events when the brightness changes, i.e. $I(t) \log (X(t)) / \log 2$ exceeds a certain threshold. The DVS is able to capture extremely fast motion with high temporal precision in diverse and harsh lighting conditions. The data stream it generates is sparse, containing only the changes and movements of a scene.

We have developed eDVS, an embedded version of the DVS technology. Its small form factor, low weight and low power-consumption enable using eDVS on mobile robots.

Project Description

We combine neuromorphic hardware - a DVS (dynamic vision sensor, silicon retina) and a SpiNNaker (SpiKning Neural Network Architecture) board - to create an artificial, spike-based version of the Hassenstein-Reichardt motion detector.

We demonstrate that the basic principle of Reichardt-style motion detection can naturally be extended from non-spiking to spiking neurons - the DVS pixels.

Via our custom interface board these pixels become digital afferent neurons in a neural network simulation (the motion detector) running in real-time on a SpiNNaker board. Since our interface is bidirectional and the power consumption of the system is on the order of 1W, we could use the perceived optic flow to stabilize and control, e.g., a flying drone.

Spike-based implementation of a Hassenstein-Reichardt motion detector

The Hassenstein-Reichardt motion detector is an intensity-based spatiotemporal correlation algorithm found in natural vision systems like the fly optic lobe\textsuperscript{4} or the vertebrate retina\textsuperscript{5}. Here, we demonstrate a spike-based version, the input of which are discrete events from a dynamic vision sensor (DVS). A DVS pixel generates an event in reaction to a local change in brightness. From these events our detection algorithm, implemented in PyNN, computes an optic flow map.

In the one-dimensional example sketched below, each photoreceptor (pixel) $p_n$ projects to two motion-sensitive neurons. Those neurons, $i_n$ and $r_n$, receive spikes not just from $p_n$ but also from the neighboring receptors ($p_{n-1} \leftrightarrow r_{n-1}$, $p_{n+1} \leftrightarrow r_{n+1}$).

Those 'diagonal' connections, however, delay the signal by a constant lag $\Delta t$. If a moving object stimulates neighboring cells in ascending (descending) order and with a temporal delay roughly matching $\Delta t$, it will generate spikes that arrive at $i_n$ ($r_n$) at roughly the same time. $i_n$ and $r_n$ are tuned to spike only if two action potentials coincide in a time window of width $\Delta t$. Therefore, they spike in response to perceived rightwards ($r_n$) or leftwards ($i_n$) motion.

Flicker can, however, trick the cells: Both $i_n$ and $r_n$ spike simultaneously, when $p_n$ spikes periodically, e.g., in response to light flickering at a period -- $\Delta t$. A flicker filter subtracting the signals of $i_n$ and $r_n$ removes this effect.