Spiking Neural Network Based Navigation Inspired by C. Elegans Thermotaxis

Chirag Shetty, Sri Nitchith, Rishabh Rawat, Nandakumar S. R, Pritesh Shah, Shruti Kulkarni & Bipin Rajendran
Department of Electrical Engineering, Indian Institute of Technology Bombay, Mumbai, India;

Introduction

▪The nematode Caenorhabditis Elegans (*C. Elegans*) is widely considered today as the model organism for studies in developmental biology

▪Among the many interesting behaviors exhibited by the nematode is its ability to track regions with constant temperatures or chemical concentrations i.e thermotaxis or chemotaxis ,*C. Elegans* migrates to regions with temperature close to their cultivation temperature (Tc), and deviating from a given isotherm by as little as 0:05 C.

▪ Inspired by the biological neural networks underlying the thermotaxis behavior of C. Elegans , we demonstrate a spiking neural circuit with timing-dependent adaptive synapses, to track contours in a two dimensional plane

▪However, unlike the C. Elegans network, our sensory neuron only uses the local variable (and not its derivative) to implement contour tracking, thereby minimizing the complexity of implementation. Also we use inputs from a simple IR LED pair measuring intensity of reflected light from arena floor, as the input to our network. The neurons in our circuit spike operate at sparse biological rates (~100 Hz)

Spiking Neural Network (SNN) structure

Structure

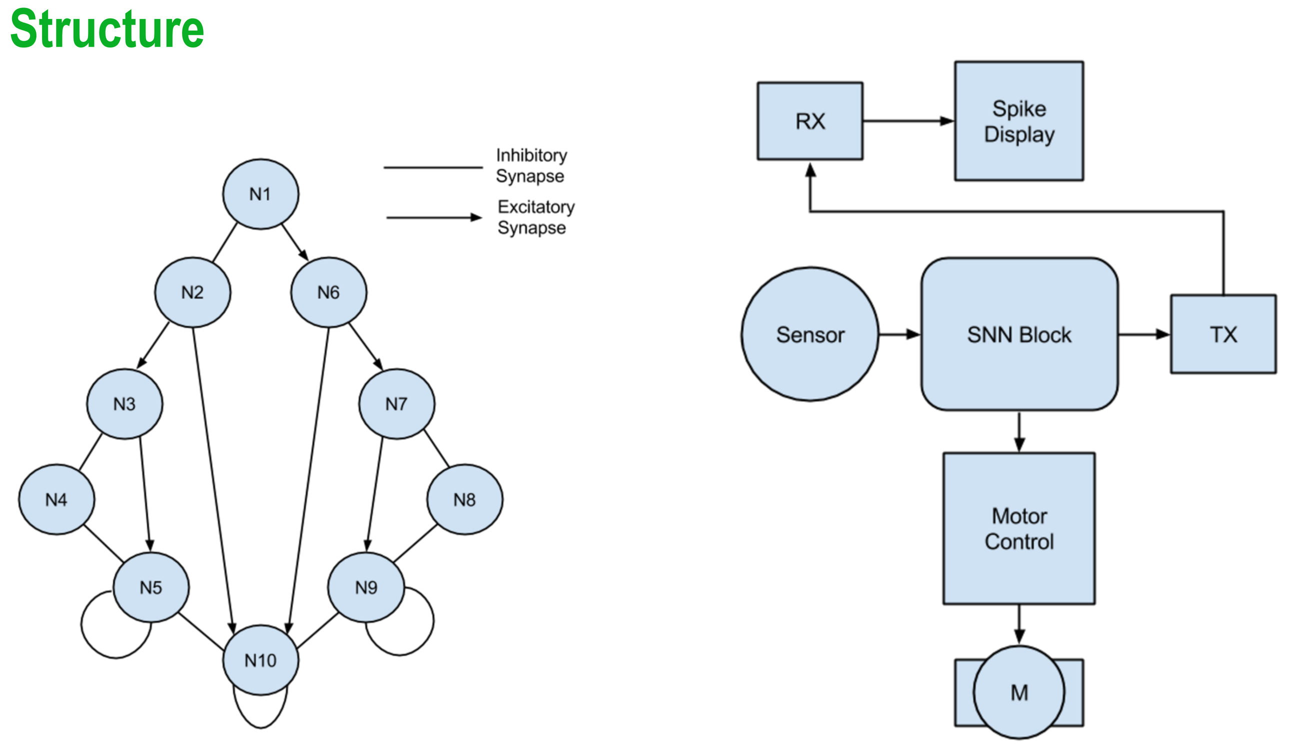

Fig 1. Schematic of the neural circuit for contour tracking. N1 is a temperature sensitive input neuron. N1 ➔N3 is a positive comparator, and N7 ➔N8 ➔N9 is a gradient detector. Similarly, N1 ➔N2 is a complementary comparator, and N4 ➔N5 ➔N6 is a gradient detector. N6 and N9 control the deterministic turns, while N10 controls the random exploration.

The 10 neuron neural circuit consists of 2 comparator and 2 gradient detector blocks. The algorithm used is as follows: If the worm is not near the desired setpoint(Ts), it should exhibit random exploratory motion. If the instantaneous temperature T is greater than the setpoint and if the worm is encountering a positive gradient, we should alter the direction of motion (here, turns clockwise). This is also true if the local temperature T is less than Ts, and the worm is encountering a negative gradient (turns anti-clockwise)

Spiking Neural Network (SNN) structure contd.

Comparator & Gradient Detector Blocks

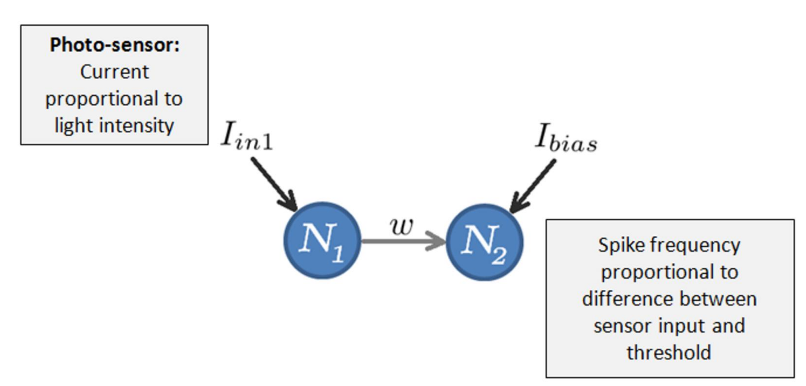

Figure 2. 1: Structure of comparator micro-circuit

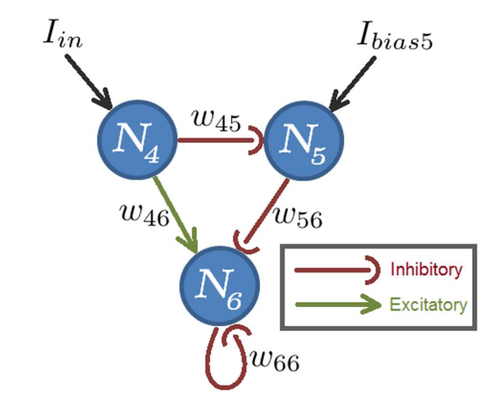

Figure 2. 2: Structure of gradient detector micro-circuit

▪In Comparator, the spike frequency of N2 is determined by the bias current Ibias and the weight w of synapse N1 to N2

▪In gradient detector, the input to the network is an analog current, Iin at neuron N4, and N6 is the output neuron. N6 spikes when the network detects a positive gradient (w.r.t time) at the input current Iin. The synapse w46 is chosen to be excitatory, while w45 and w56 are inhibitory. Signal propagation through N4 ➔ N5 ➔ N6 takes longer than through the direct path N4 ➔ N6. Since the currents in these paths have opposite signs, the effective spike frequency of N6 should mimic a derivative operation

Simulation Results

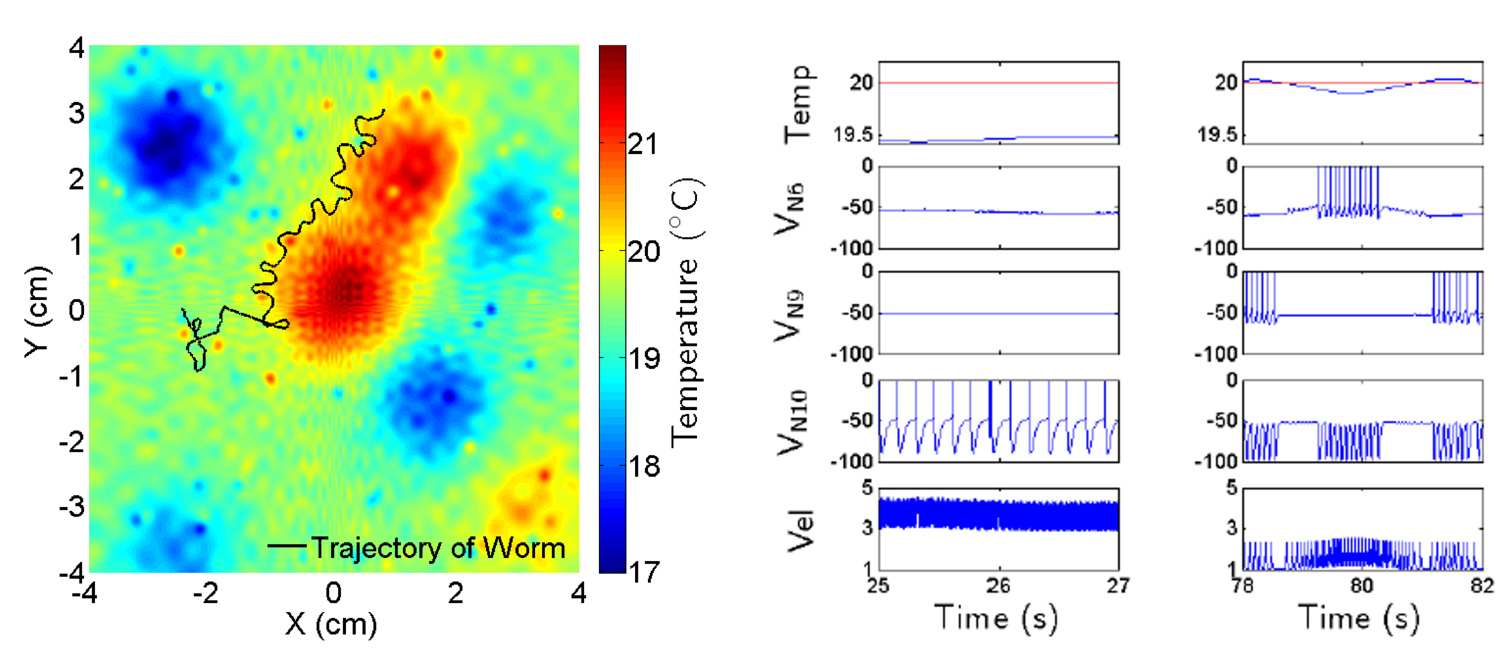

Figure 2. shows a typical motion profile executed by our worm for a set-point of Ts = 20 C. Initially, the worm executes random exploratory motion till it comes to the vicinity of Ts and then tracks the isotherm, with standard deviation around the isotherm maintained at 0:05 C. The spike patterns in the network during random motion and tracking is shown in the adjacent figure.

▪ The Izhikevich model is used in simulating all the 10 neurons.
In our model, the worm is continuously moving. It is believed that the worm executes thermotaxis by performing a biased random walk by switching between periods of long forward movements called 'runs' and sudden switches in directions called 'pirouettes'. It is found that as the worm approaches the desired temperature, the frequency of pirouettes decreases and run length increases.

Hardware Implementation

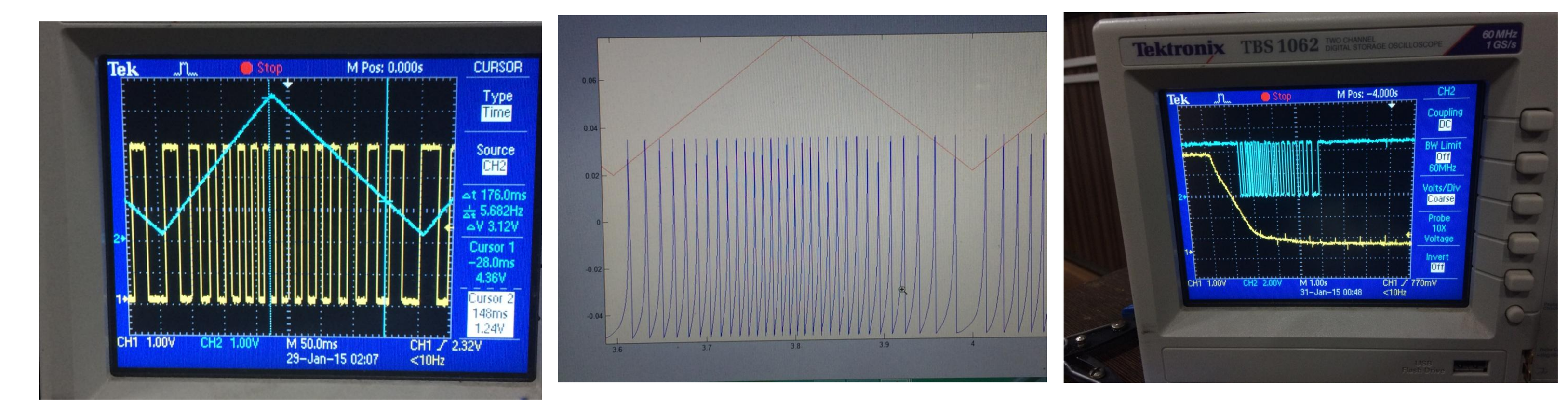

Fig 3.1: Hardware output for ramp *Fig 3.2: Expected output from simulations* *Fig 3.3: Hardware Gradient detector output*

System Description

▪The on-board circuit of the robot has a sensor, which receives local external input, and microcontrollers, which simulate the neural network. We use a parallel combination of microcontrollers to simulate ten Izhikevich neuron models which are interconnected as shown in Fig. 1

▪Besides 10 microcontrollers, each solving the differential equation corresponding to the Izhikevich model, there's a n additional microcontroller that interprets the spike output from N5, N9 and N10 and converts it into appropriate signals to the motor driver

▪The effect of spikes from N5, N9 and N10 are turn clockwise, turn anticlockwise and randomly select a direction and turn, respectively. The spike outputs of these neurons is transmitted wirelessly through an RF pair and then displayed on the laptop

Conclusions

▪Spike based real-time decision making can be used to perform conventional activity like contour-tracking.
▪ Putting together multiple independent entities that behave like neurons, producing spikes according to the neuron models, results in a desirable behavior similar to thermotaxis.

Acknowledgements

We gratefully acknowledge valuable contributions, through discussion, by Mr. Ashish Bora and Mr. Arjun Rao of IIT Bombay.
We also thank Tinkerers' Lab and Wadhwani Electonics Lab of IIT Bombay

References

[1] A. Bora, A. Rao and B. Rajendran. Mimicking the worm - an adaptive spiking neural circuit for contour tracking inspired by C. Elegans thermotaxis. International Joint Conference on Neural Networks, 2014.

Contact Information:
Chirag Shetty chiragshetty@iitb.ac.in | Sri Nitchith 120070047@iitb.ac.in | Bipin Rajendran bipin@ee.iitb.ac.in