ECE 2195 Neuromorphic Systems Design – Homework #3

Total 100 points Due 02/14/2024

Problem 1. Neuromorphic Audition using Microphone (50pts)

Use your laptop/desktop microphone and convert it to a neuromorphic event-based audio sensor that models a 1D cochlea, as discussed in lecture 7. Submit your code and resulting audio recording and spectrum plots.

Use the starter code provided in HW3_cochlea.py to record and plot the audio signal from your microphone. Record an audio sample (.wav file) of identical duration (say 1 second) for each of the 3 digits, "zero", "one" and "two".

1. Break down the input audio signal into 4 time slices, each equal to 0.25*time period of each spoken word (i.e. 0.25s for 1s duration). Apply FFT (Fast Fourier Transform) on each slice of the sampled audio stream. Assume the maximum frequency to be 10kHz. Get 4 FFT outputs for each spoken word. Plot the spectrum output of the audio **(20pts)**
2. Apply ideal BPF (band pass filter) with 8 center frequencies starting from 750Hz with a step of 1kHz, such as 1,2,3….,8kHz. Bandwidth of each BPF is 500Hz around the corresponding center frequency. Integrate the spectral content in each of these bands to estimate the energy/power level. Make a bar plot of energy/power vs center frequency. **(15pts)**
3. Apply a threshold power level to generate events from each band. The threshold is set to 0.25x of the maximum power level recorded. If the level is above the threshold the output event is +1, else 0. Since each FFT is then split into 8 frequency bands and quantized with a threshold, the final result is a 8x4 matrix for each spoken digit. **(15pts)**

In all cases, record and submit audios of spoken digits to prove your results. You can tune the threshold to arrive at the optimal representation of the spoken digits i.e. the 8x4 matrix should be unique for each spoken digit. Recommended platform is python (Jupyter/IDLE/PyCharm) along with PyAudio. Use your choice of platform and software. For Matlab, use getAudioDevices function to open mic and record.

Problem 2. Neuromorphic Tactition using Integrate-and-Fire Neuron (30pts)

Consider the integrate-and-fire neuron model equations discussed in lecture 8. Assume C_{MEM} = 1pF, I_{INJECT} = 1µA, Vth = 1V, V_{RESET} = 0, g_{leak} = 0. Use Matlab/Python for plotting.

1. Implement the model in your choice of platform. Plot the output membrane voltage, V_{MEM} as a function of time. Calculate the spike frequency when I_{INJECT} = 0.5µ, 1µ and 2µA. **(10pts)**
2. The membrane capacitance C_{MEM} is modulated by external applied pressure. Assume $\varepsilon_0 = 8.854\text{x}10^{-12}$F/m, ε_r = 10, A = 1.13sq.mm and d_0 = 1mm. Assume a simple linear relationship between d and applied pressure, P, i.e. as P increases, d decreases.

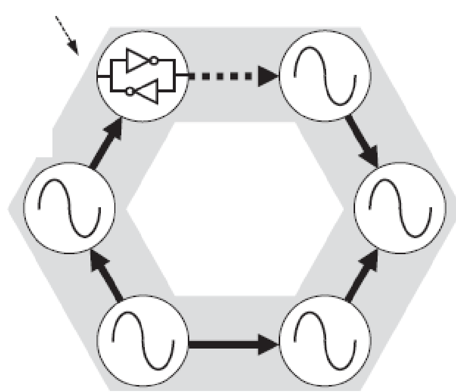
   $$d = d_0 - \kappa P$$

   Calculate C_{MEM} as a function of Pressure and plot the curve as pressure varies from 1N to 10N. κ = 0.01 mm/N. **(5pts)**

3. Repeat V_{MEM} plots for 10 steps between 1N to 10N applied pressure. Plot spiking frequency vs pressure. Is the plot linear? Comment on the pressure sensitivity. Can we determine the pressure applied based on the output spike rate of the neuron? What is the smallest step of pressure that can be distinguished in this case? **(15pts)**

Problem 3. Neuromorphic Motor Control for Gait Analysis (20pts)

Consider a 6-stage ring oscillator (similar to the diagram below) to model different phases of rhythmic motion in a Central Pattern Generator (CPG). Assume the output of each oscillator to be a sine wave of normalized amplitude 1 and frequency 1Hz. The output of each stage differs only in the phase. Use Matlab/Python for plotting.



1. Plot the sine wave outputs of the 6 stages. How many unique phases are possible with this ring oscillator? **(5pts)**
2. In order to generate a unique vector to distinguish the phases (similar to problem 1), we use the cross-correlation of the output of the first stage with output of every other stage.

Plot the cross-correlation outputs. This can be done by multiplying the sine wave outputs of each stage. **(5pts)**

3. Set a threshold level (say 0.1) on the cross-correlation outputs to generate events/spikes. Find the unique code for each phase using the output of the threshold comparator. **(10pts)**