Impact of Memristor Degradation on Image Classification

Aalvee Asad Kausani [1], Caiwen Ding [2] and Mehdi Anwar [1]

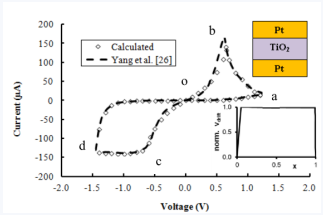
[1] Department of Electrical and Computer Engineering, [2] Department of Computer Science & Engineering, University of Connecticut, Storrs, CT 06269, USA

Abstract

We report the reduction in accuracy of an Artificial Neural Network (ANN) for Image classification due to the degradation in memristors employed as electrical synapses in the network.

Introduction

- Memristors are two-terminal analog devices and demonstrate hysteresis in I-V characteristics enabling the non-volatile memristive property.

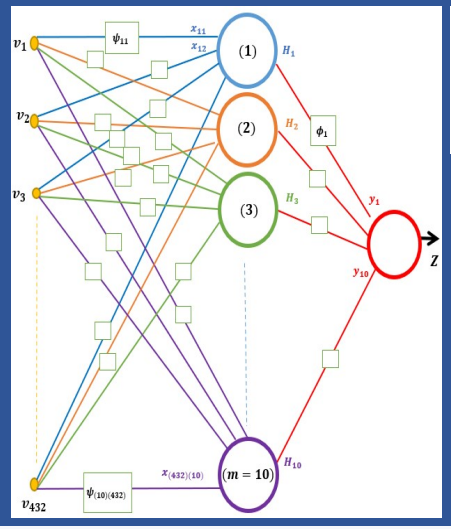


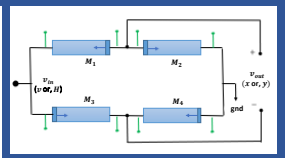
[1]

- Memristors qualify to emulate the electrical synapses in hardware for ANN for their analog property and data retention capability. Synapses are the bridges between computational neurons and act to scale and transmit signals.
- Collapse in the I-V characterization [2] asserts the idea of gradual degradation in the switching property of memristors [1].
- We simulate an ANN with memristors and observe the implication of device degradation on the accuracy.

Architecture and Modeling

The design of 432 input-1 hidden layer-1 output neural network and its learning scheme have been adapted from [3]. The green boxes in the schematic of the architecture are memristor bridges that emulate synapses. The structure and functionality of a bridge is illustrated. We model ideal memristors using the analytical approach in [1]. Training implies setting up the memristor bridges with appropriate values of synaptic weight in an iterative process. **We applied a new method for translating the trained parameters (synaptic weights) into physical attributes to update the state of the memristors during training.** Degradation is modeled as a factor that emulates gradual deterioration in the physical property of memristors causing unwanted changes in synaptic weights.





$M(t) = \text{Memristance}$

[3] $M(t) = \frac{v(t)}{i(t)}$

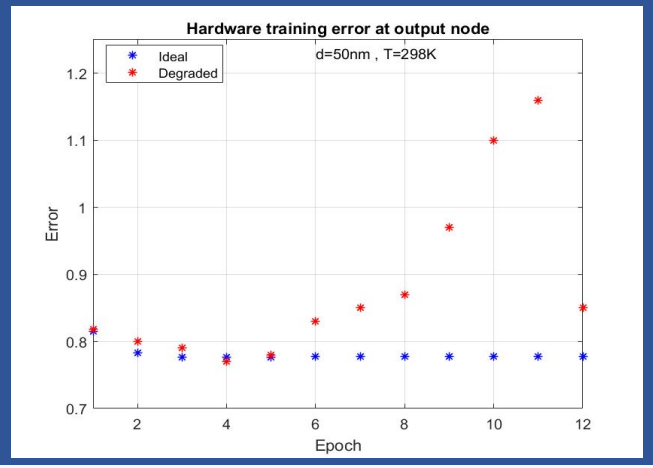
$\psi = \frac{M_2}{M_1 + M_2} - \frac{M_4}{M_3 + M_4}$

$V_{out} = \psi V_{in}$

ψ = Synaptic Weight

Training the Network

Four cases depending on memristor length and operating temperatures were observed. The networks were trained to perform as a binary classifier to distinguish between images of Huskies and non-Huskies. We train the networks for 12 epochs and choose 0.01 as the degradation factor. The average training error at the output slowly decreases for a network with ideal memristors. However, average error increases for a network with degrading memristors indicating an inefficient training.



Testing the Network

- A network with degrading memristors yields reduced accuracy compared to a network with ideal devices.
- If the network is trained longer (higher value of epoch), gradual degradation causes severe drop in performance, and we observe 0 accuracy when the memristors collapse.
- Larger value of degradation factor emulates faster deterioration in devices that results in collapsed devices in earlier epochs.

Memristor length Temperature	Classification Accuracy	
	Ideal Memristors	Degrading Memristors
$50\ nm\ ,\ 298\ K$	70%	50%
$50\ nm\ ,\ 600\ K$	90%	50%
$25\ nm\ ,\ 298\ K$	70%	50%
$25\ nm\ ,\ 600\ K$	70%	50%

Conclusion

A hardware with memristors dedicated for AI applications cannot be reliably trained with large number of iterations since gradual degradation of memristors leads to compromised performance.

Contact Information

Mehdi Anwar
Professor, Department of Electrical & Computer Engineering
University of Connecticut, Storrs, CT 06269, USA
a.anwar@uconn.edu

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