

A Hybrid-Digital-Mixed-Signal Computing Platform for Accelerating Swarm Robotics

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Semiconductor Research Corporation under grant JUMP CBRIC task ID 2777.006.

Motivation

Swarm Robotics

Model-Free



Multi-robot patrolling



Multi-robot predator-prey

$$\text{ReLU}(\sum x_i w_i)$$

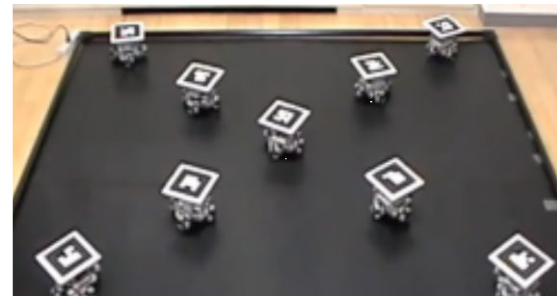
$$\tanh(\sum x_i w_i)$$

linear operation
nonlinear activation

Model-Based



Obstacle/collision avoidance

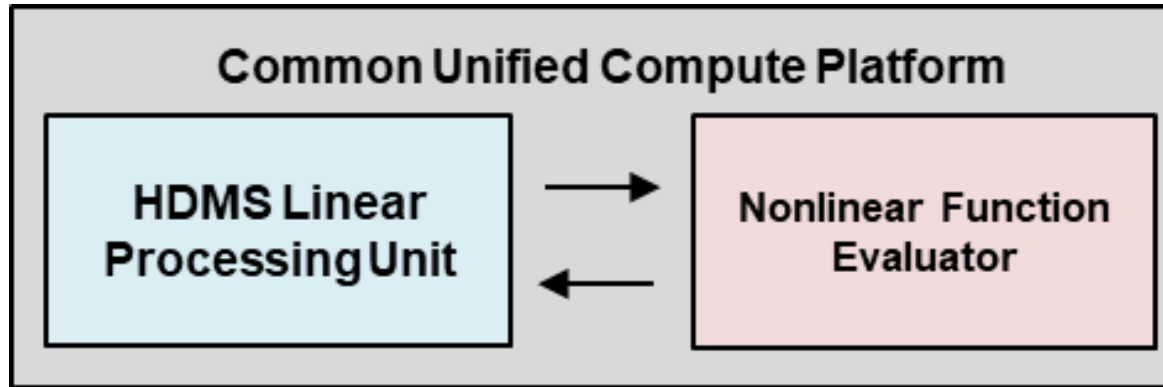


Pattern-formation

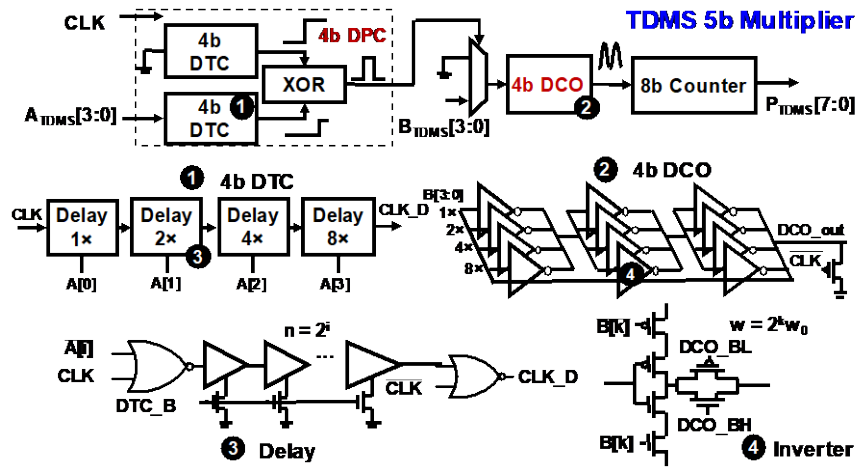
$$\sum x_i \cos(y_{id})$$

$$\sum x_i \tanh(\text{sqrt}(y^2 - y_1^2)/Q)$$

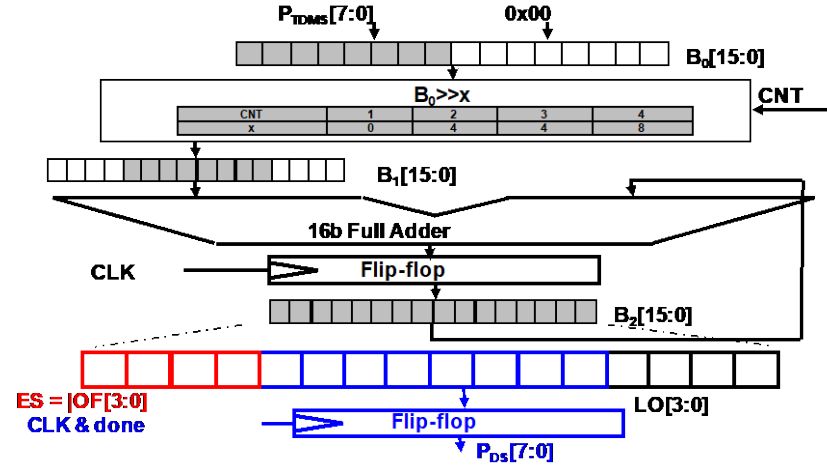
Nonlinear function
Linear operation

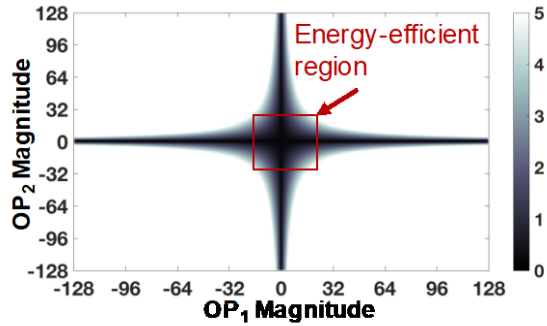


Linear Processor Circuit Diagram

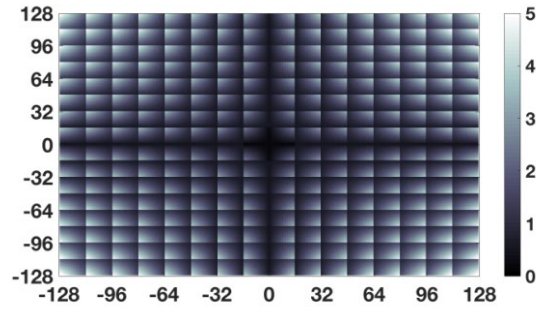


5b-8b Digital Add-shifter





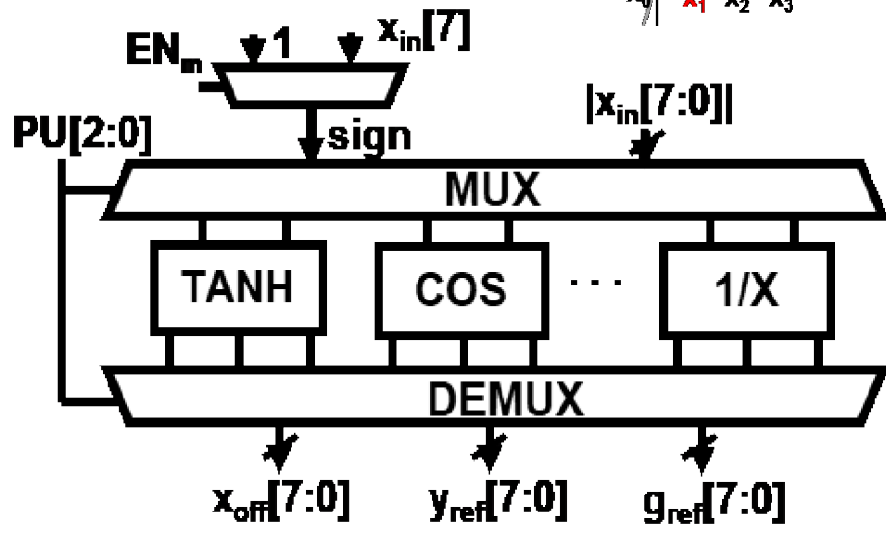
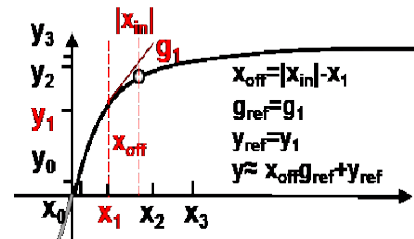
Energy/MAC TD-MS [2]



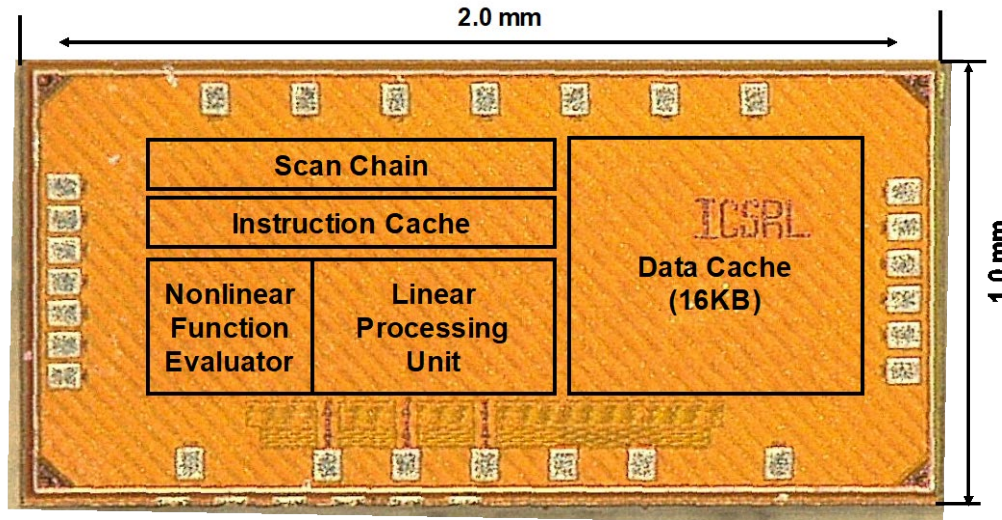
Energy/MAC HDMS (This Work)

No. Bits	TD-MS		HDMS	
	Average	Worst	Average	Worst
3	0.10	0.49	0.19	0.52
4	0.14	0.56	0.16	0.61
5	0.28	0.72	0.29	0.74
6	0.64	1.74	0.69	0.94
7	2.21	3.86	0.70	1.02
8	5.82	9.32	0.69	1.27

Energy/MAC (Normalized to Digital)

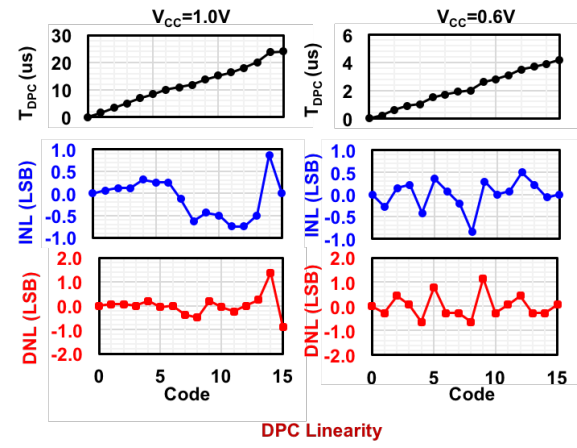
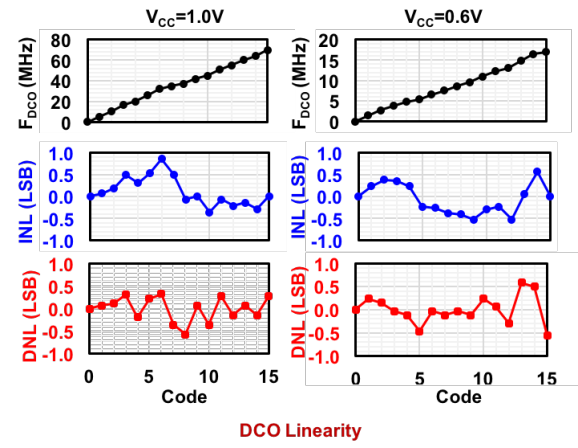


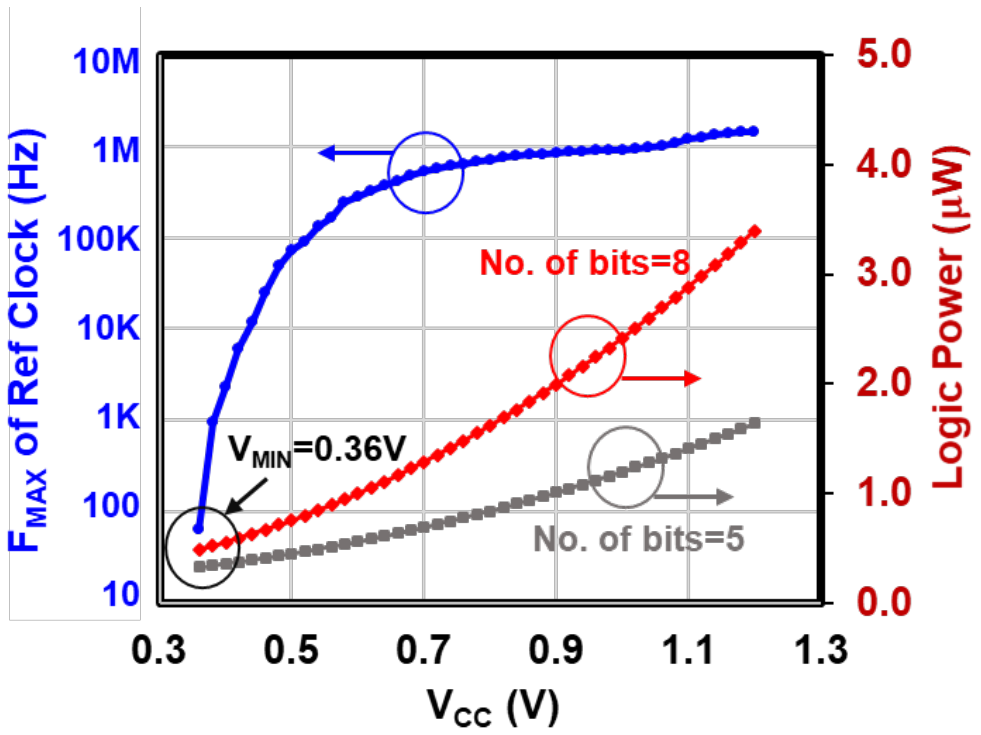
Chip characteristic



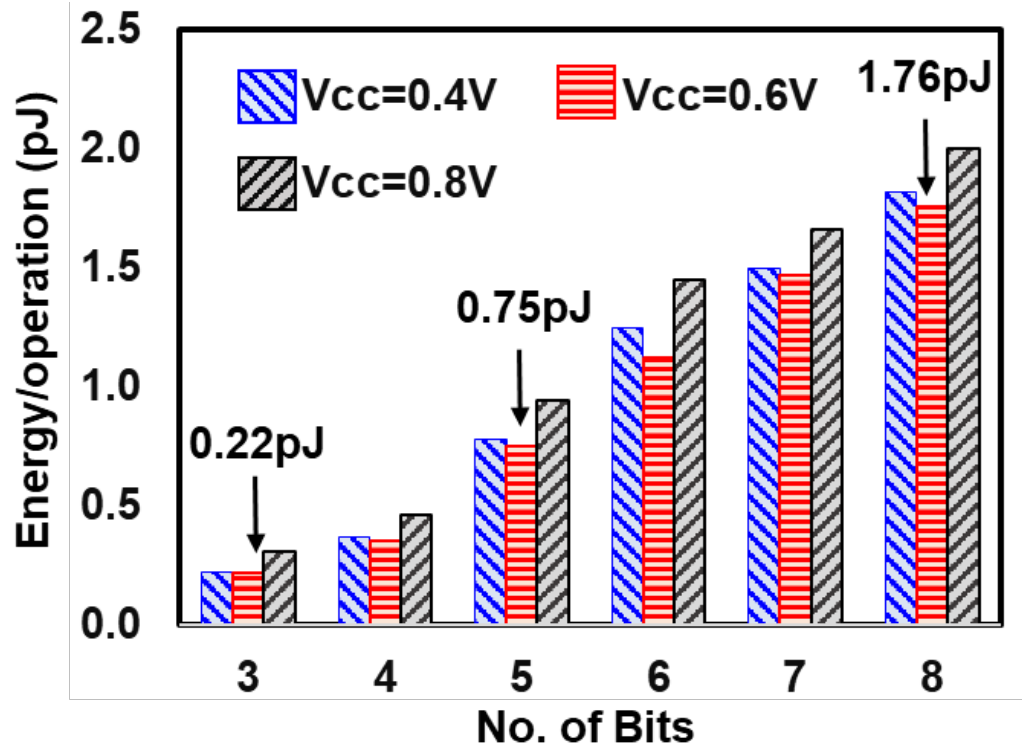
Chip Characteristics	
Technology	65nm 1P9M CMOS
Die area	1mm*2mm
Testing interface	QFN package
Pin Count	28

Nonlinearity measurements



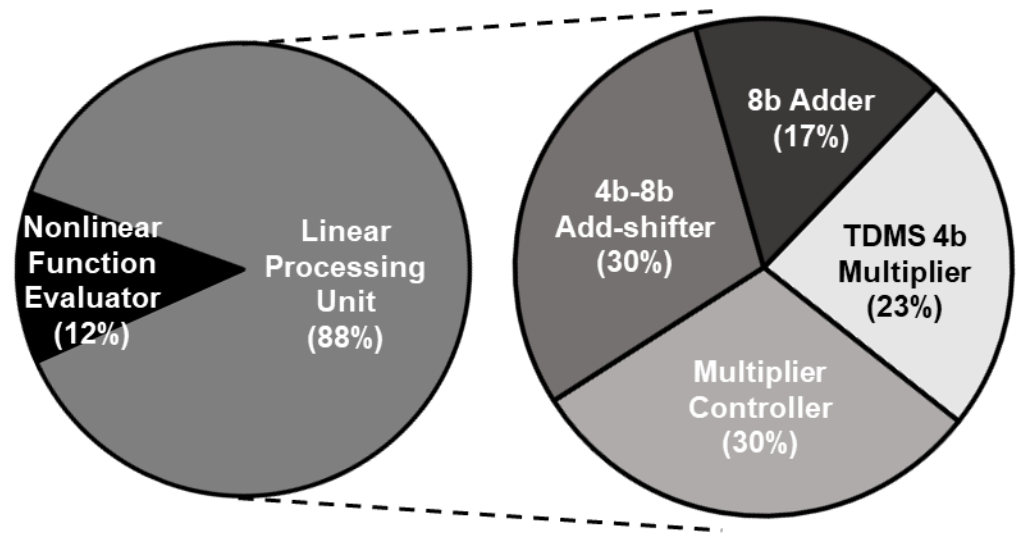


Power-performance trade-off



Energy/MAC for varying bit-width

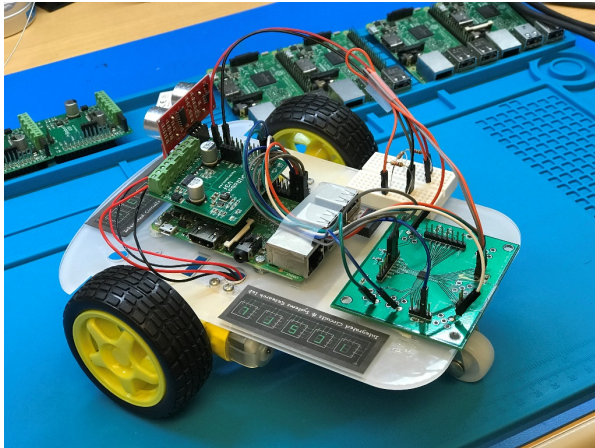
Power breakdown



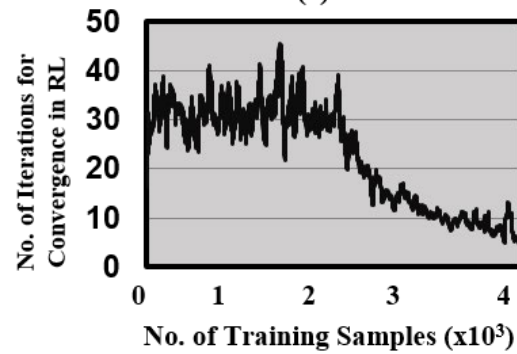
Power break-down across functional modules

Comparison table

	This work	[2]	[3]	[4]	[5]	[6]
Application	Swarm intelligence	Autonomous micro-robotics	CNN Inference	DNN Inference	CNN Inference	CNN Inference
Optimization algorithm	Cooperative RL/potential field	Reinforcement Learning	none	none	none	none
Learning/Training	Online in real time	Online in real time	offline	offline	none	offline
Technology	65nm	55nm	180nm	65nm	65nm	65nm
Area	2mm ²	3.4mm ²	3.3mm ²	16mm ²	16mm ²	16mm ²
On-die SRAM	16 KB	200 B	144 KB	36 KB	490.5 KB	181.5 KB
Resolution	3-8b	6b	4b-16b	16b	16b	16b
Power	0.3-3.4 uW	650 uW	7.5-300 mW	45 mW	6.57 mW	278 mW
Frequency	1KHz-1.5MHz	67.5 MHz	200 MHz	125 MHz	10 - 100 MHz	200 MHz
Supply voltage	0.4-1V	0.4-1V	1V	1.2V	0.7-1.2V	0.82-1.17V
Performance/Watt	1.1-9.1 TOPS/W	3.12 TOPS/W	0.26-10TOPS/W	1.42TOPS/W	11.8 - 19.7 GOPS	0.21TOPS/W



(a)



(b)