sEMG-based Gesture Recognition with Spiking Neural Networks on Low-power FPGA

Matteo A. Scrugli, Gianluca Leone, Paola Busia, Paolo Meloni,
Università degli Studi di Cagliari, Italy

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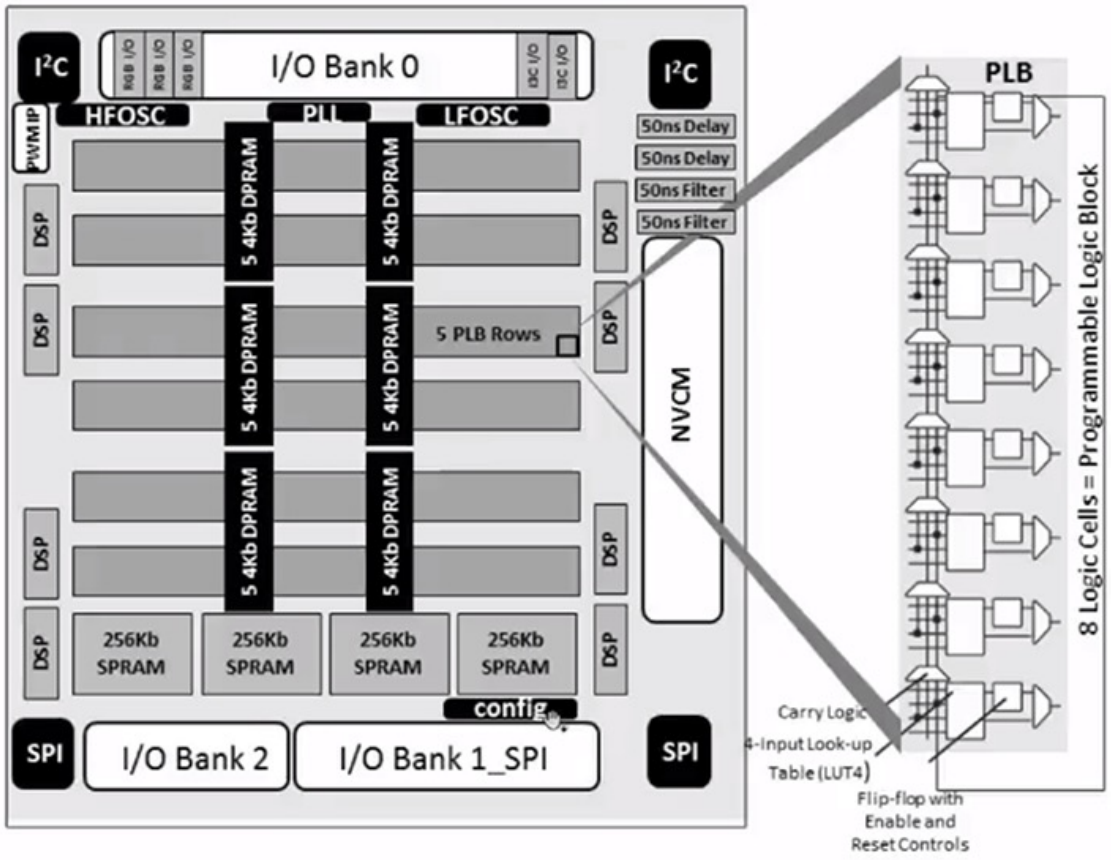
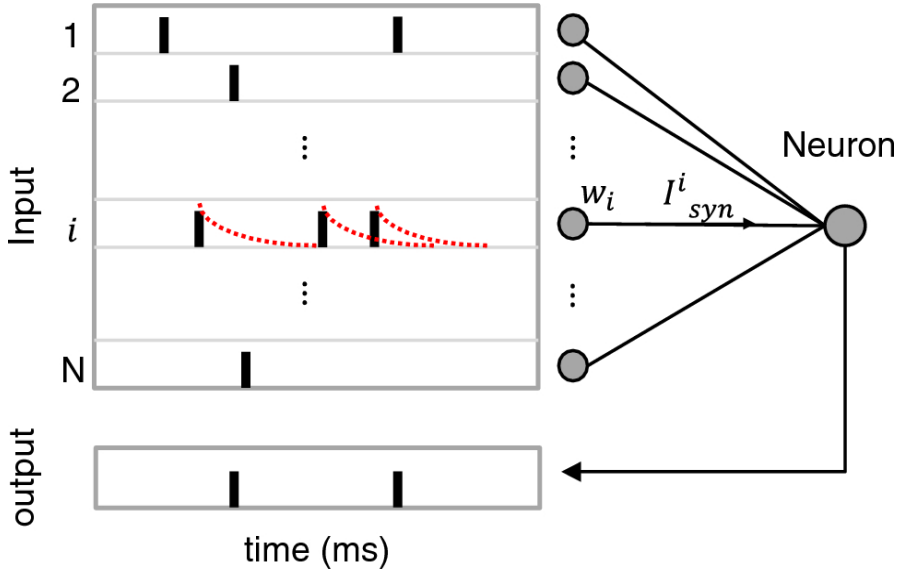
SNNs on FPGA

- SNNs
  - Event-based for energy efficiency





- FPGA as a target
  - DSPs
  - Flexible BRAMs
  - Additional RL
    - Use-case flexible encoding/deconding
    - Emulate event-based with additional clock-based circuitry
  - Affordable costs

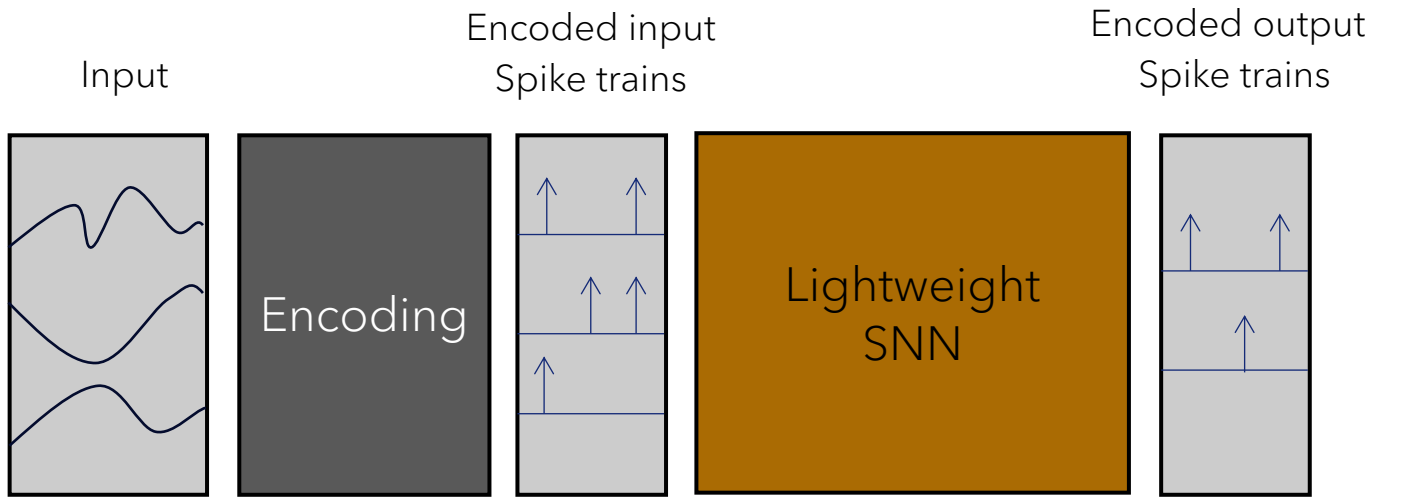
State-of-the-art

Work	Dataset	Encoding	Classes	Accuracy	Device	Energy	Power	Mops
Behrenbeck, J. 2019	custom 4 subjects	Delta	4	84.8%	SpiNNaker	N.R.[1]	1-4 W	N.R.
Cheng, L. 2021	custom 8 subjects	Population	8	94.4%	N.R.	N.R.	N.R.	0.013
Tanzarella, S. 2023	custom 5 subjects	HD-sEMG Decomposition	10	95%	Jetson	0.97 mJ	100 mW	7.97*
Xu, M. 2023	custom 10 subjects	Event-drive Differential	6	98.78%	N.R.	N.R.	N.R.	6.57
Vitale, A. 2022	NinaPro DB5	Delta	12	74%	Loihi	246 mJ	41 mW	11.56*
Our	NinaPro DB5	Delta	12	85.6%	FPGA	35.68 uJ	1.7 mW	2.336

[1] Not Reported.
* Estimated from the paper.

Approach overview

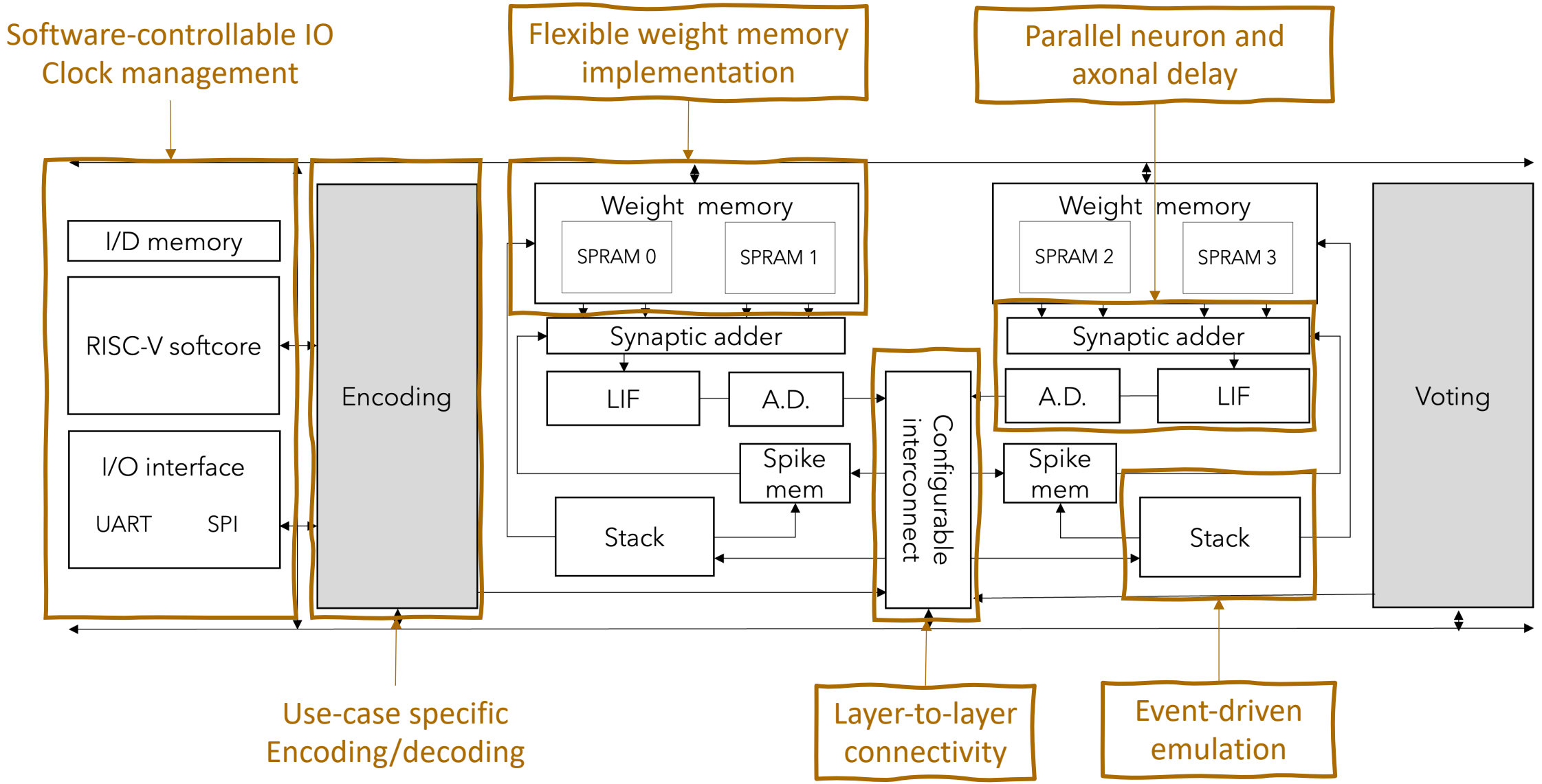
Thalmic Myo Armbands



Limited number of channels

AI-based analysis result

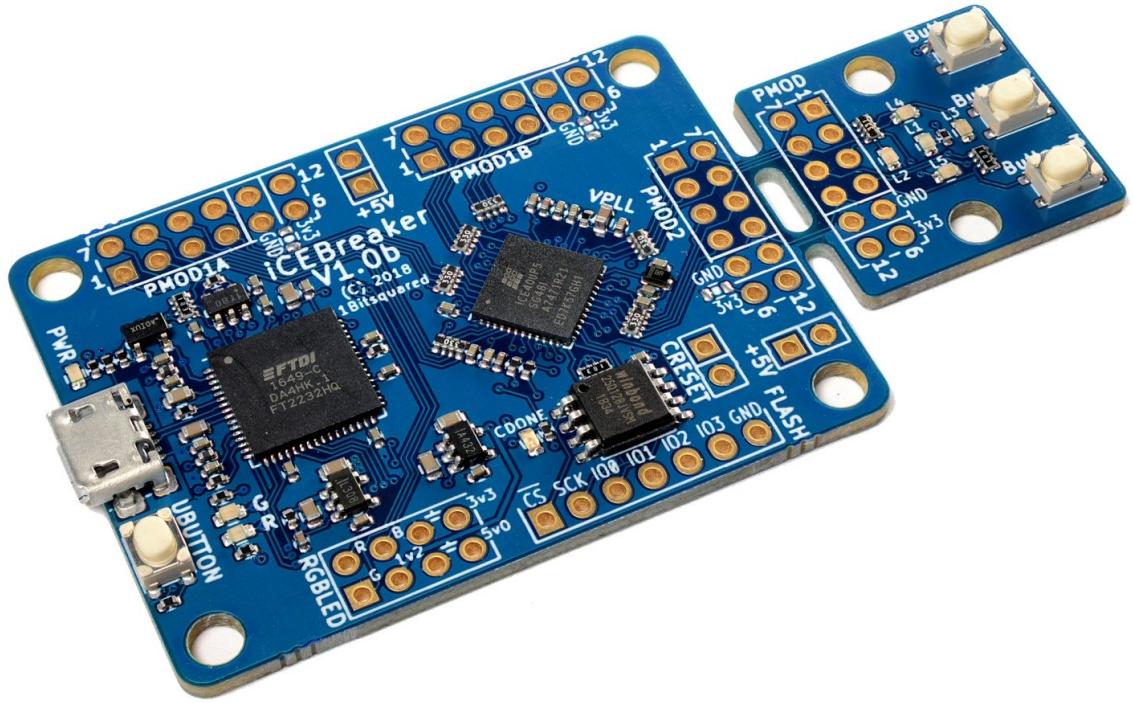
SYNtzulu: architecture



Assessment: low-end implementation

Lattice iCE40UP5k FPGA

- 5280 logic cells (4-LUT + Carry + FF)
- Around 1 Mbit on-chip RAM
- PLL, 2 x SPI, 2 x I2C hard IPs
- Two internal oscillators (10 kHz and 48 MHz) for simple designs
- Eight DSP multiplier blocks

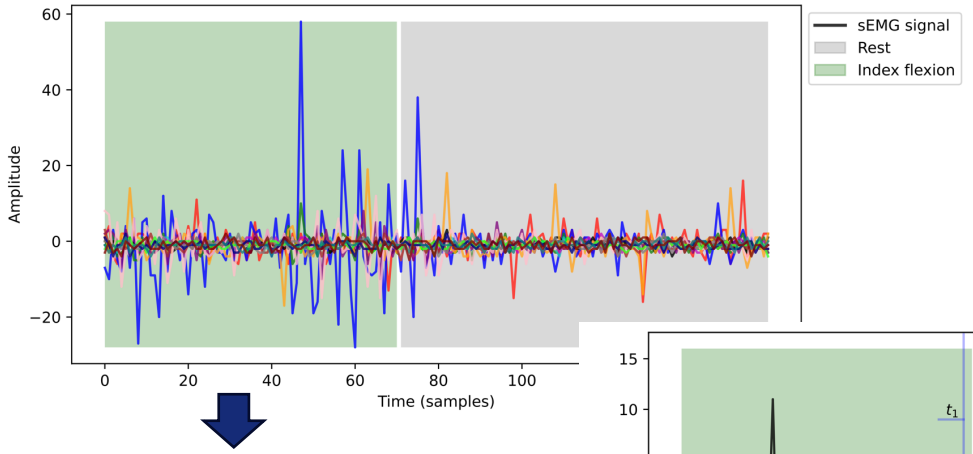


LUT & FF	DSP	BRAM	SPRAM
4506 (85%)	2 (25%)	21 (70%)	4 (100%)

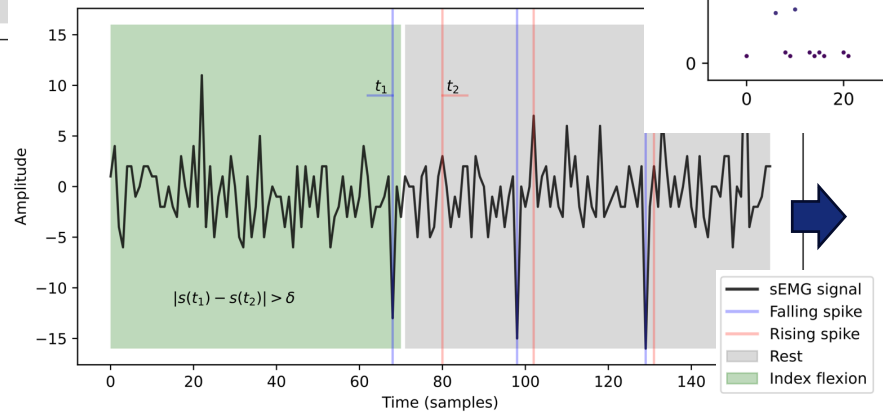
Data encoding and output classes

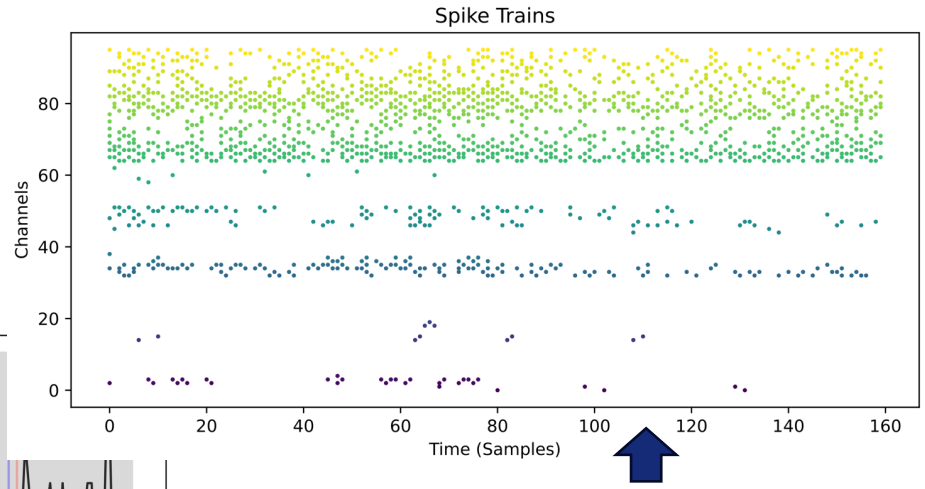
Gestures recognition from Myo Gesture Control Armband

Raw signal → Encoding: delta modulation → SNN → Classification results



Spikes are found for each channel according to the delta modulation algorithm





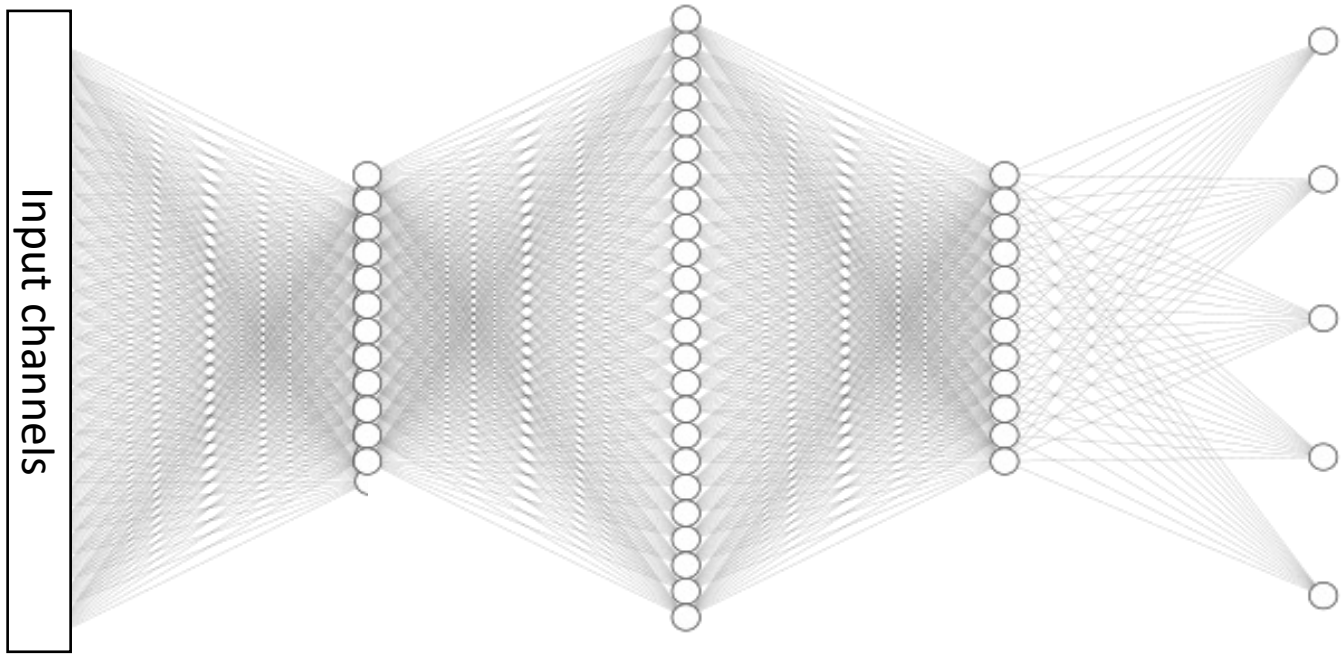
The first and second derivative signal is calculated for each channel, and two spike signals are associated with each signal (raising, falling)

Exercise A		
1	Index flexion	
2	Index extension	
3	Middle flexion	
4	Middle extension	
5	Ring flexion	
6	Ring extension	
7	Little finger flexion	
8	Little finger extension	
9	Thumb adduction	
10	Thumb abduction	
11	Thumb flexion	
12	Thumb extension	

Dataset: Pizzolato et al., Comparison of six electromyography acquisition setups on hand movement classification tasks, PLOS One, 2017

SNN and training

- Feed-forward SNN - 4 FC layers
- PyTorch package **SLAYER** (Spike LAYER Error Reassignment)



Input channels	L1	L2	L3	L4	Max axonal delay	Loss	Learning rate	Patience
96	64	128	64	13	62	SpikeRate	Up to 10e-5	40 epochs

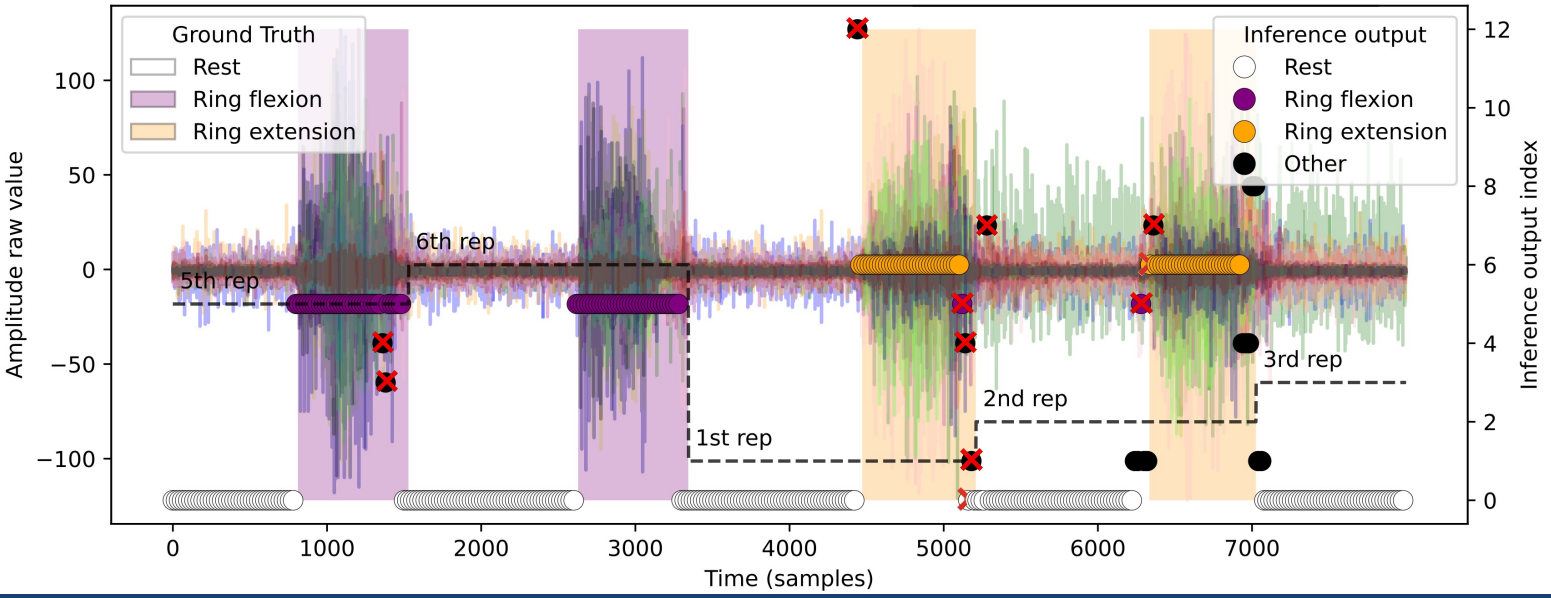
Accuracy

- Accuracy equal to 85.6%.
- 45% of the errors are concentrated in the first row and first column of the confusion matrix.

True Labels	Rest	Idx Flx	Idx Ext	Mid Flx	Mid Ext	Ring Flx	Ring Ext	Lit Flx	Lit Ext	Thm Add	Thm Abd	Thm Flx	Thm Ext
Rest	7078	36	1	28	43	1	4	26	1	39	86	2	32
Idx Flx	62	268	30	15	21	5	17	11	0	0	2	2	2
Idx Ext	31	23	224	8	12	3	1	0	0	0	2	0	0
Mid Flx	30	31	3	285	14	7	8	13	3	3	0	0	0
Mid Ext	17	4	3	0	244	8	4	5	7	0	2	0	0
Ring Flx	43	8	2	12	12	258	2	14	2	3	0	2	2
Ring Ext	39	30	3	17	36	8	218	7	3	2	0	0	10
Lit Flx	48	5	5	6	13	18	26	237	7	10	6	3	11
Lit Ext	52	0	0	5	5	10	13	13	253	0	13	7	0
Thm Add	7	10	0	0	0	0	10	4	0	161	6	70	7
Thm Abd	71	2	4	0	0	0	2	3	3	7	190	17	19
Thm Flx	21	0	4	0	0	0	0	0	0	64	2	166	10
Thm Ext	32	0	10	2	2	0	0	7	2	9	3	6	252

Predicted Labels

- Network outputs are filtered. If an output is isolated, it is considered the last valid output.

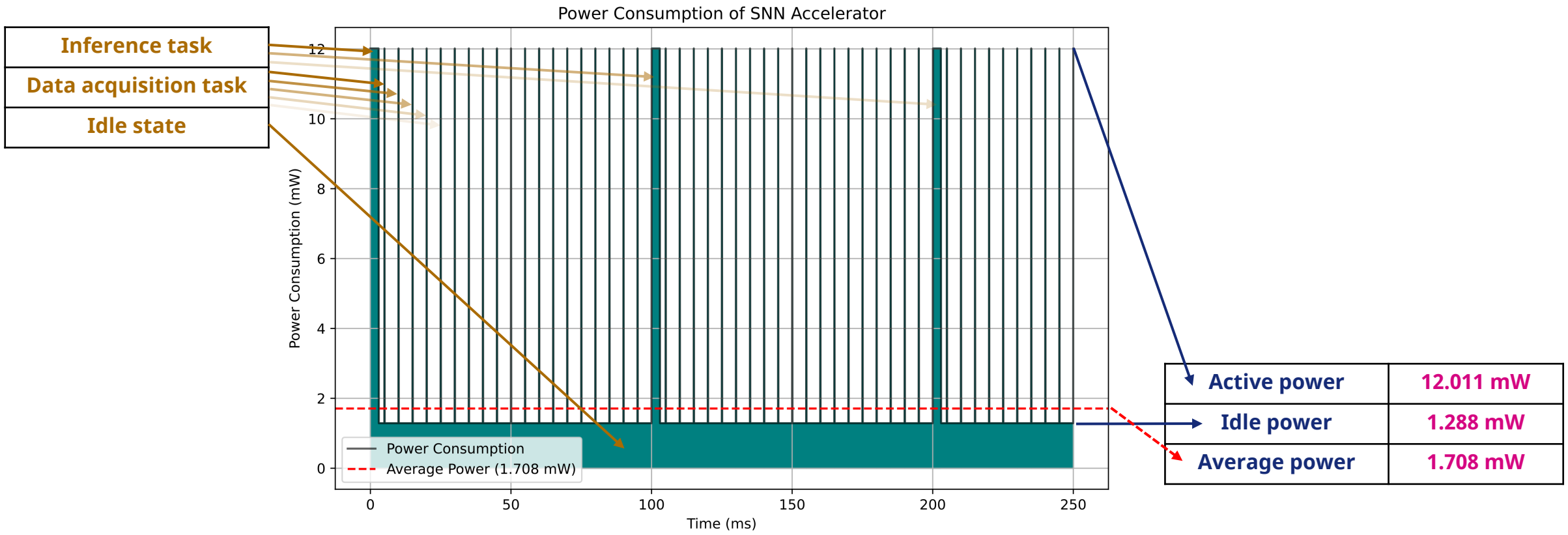


Repetitions 5 of each exercise were considered to comprise the test set.

Accuracy comparison

Vitale, A. 2022	Our work
Common aspects	
NinaPro DB5 data	
Delta encoding method	
12 classes	
Divergent aspects	
Loihi platform	Lattice FPGA
100 mW of power consumption	1.7 mW of power consumption
8 sEMG channels	16 sEMG channels
Repetition 3 and 5 in the test set	Repetition 5 in the test set
Accuracy up to 74%	Accuracy up to 85.6%
11.5 MOPS	2.3 MOPS

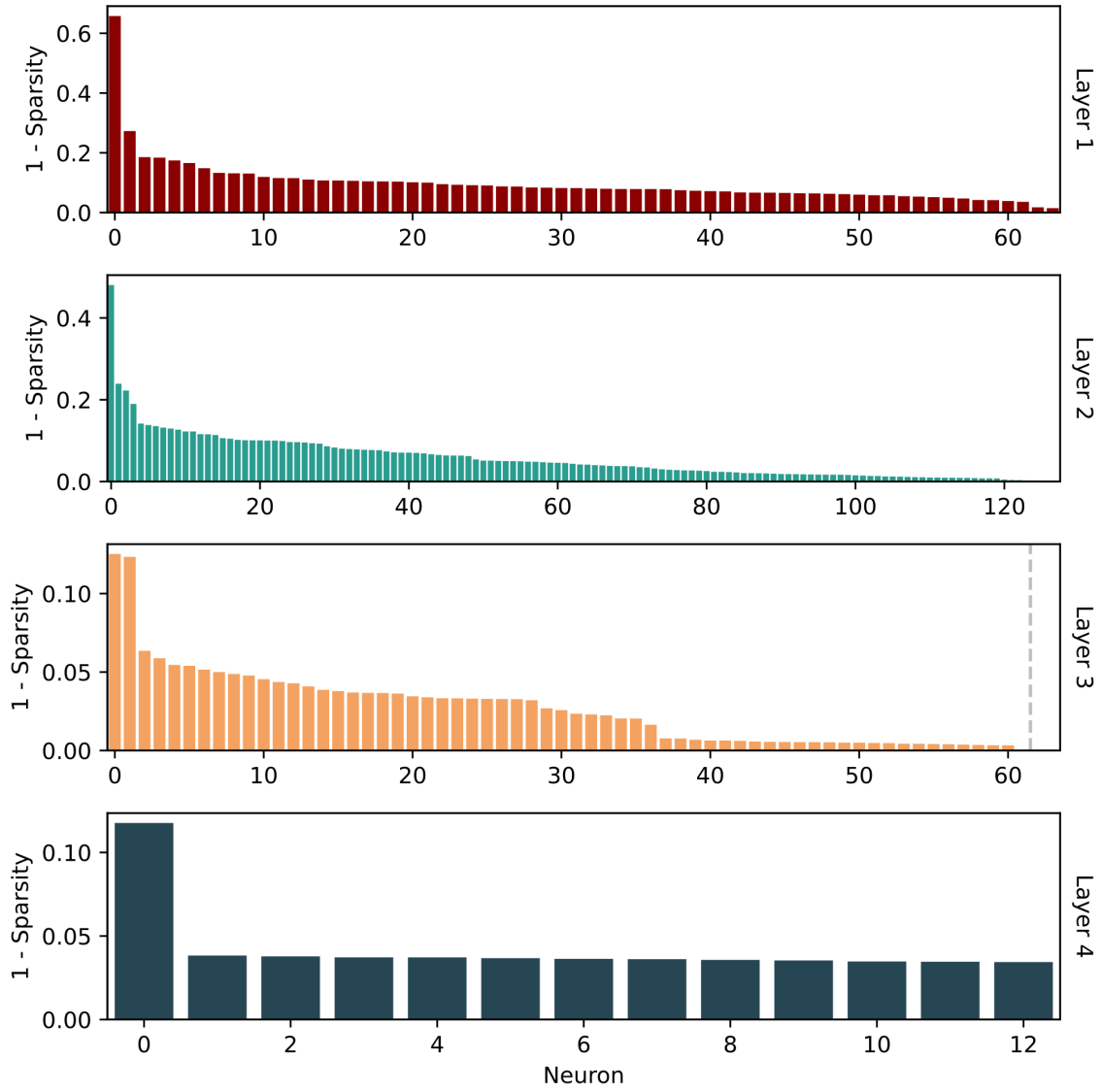
Power consumption



- Dynamic Frequency Scaling with two system frequencies: 10KHz and 22.5MHz

Sparsity and inference time

Sparsity	**90.99%**
Effective sparsity	**77.11%**
Inference time	**2.9 ms**
Inference period	**100 ms**



Conclusion

- Real-time sEMG classification system.
- High classification accuracy at the state of the art.
- Optimized for Lattice iCE40-UltraPlus FPGA and model for operational efficiency.
- Low Power Consumption.