A 16-channel, 1-Second Latency Patient-Specific Seizure Onset and Termination Detection Processor with Dual Detector Architecture and Digital Hysteresis

Email: czhang@masdar.ac.ae

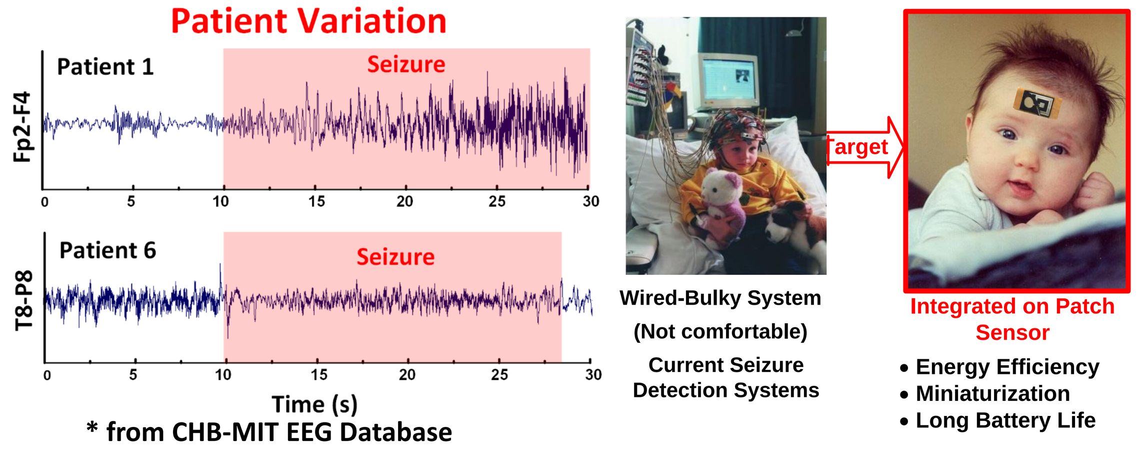
Chen Zhang, Muhammad Awais Bin Altaf, Jerald Yoo

Masdar Institute of Science and Technology, Abu Dhabi, United Arab Emirates

I. Motivation

Some Facts About Epilepsy

- > 65 million people affected worldwide[1]
- ~ 1.2 million Patients Do NOT Benefit From Anti-Epileptic Drugs
- Patient-to-Patient and Age-to-Age Variation is Huge
- Min. 16-ch EEG needed for Seizure Detection[2]
- Termination detection is needed for controlling electrical stimulation or drug release



II. Problems & Solutions

Issues with Existing Designs

- Limited # of channels (≤8) → S1
- High power consumption[7]-[8] → S1
- High resource utilization[5] → S2
- High system latency (2s)[4]-[5] → S2
- High detection Delay (13.8s)[6] → S2
- Low accuracy & high false alarms[4] → S3
- No seizure termination detection → S4

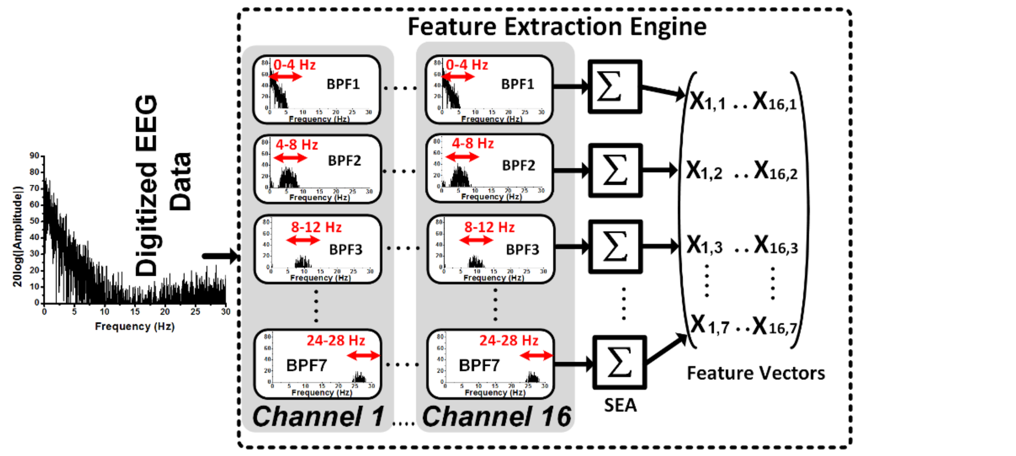
Solutions

- S1. Frequency-Time Division Multiplex BPF
- S2. Feature Extraction with Overlapped-Sliding Window
- S3. D²A-LSVM architecture + Digital Hysteresis
- S4. Weight-And-Average (WAA) Algorithm

III. Feature Extraction (FE) Engine

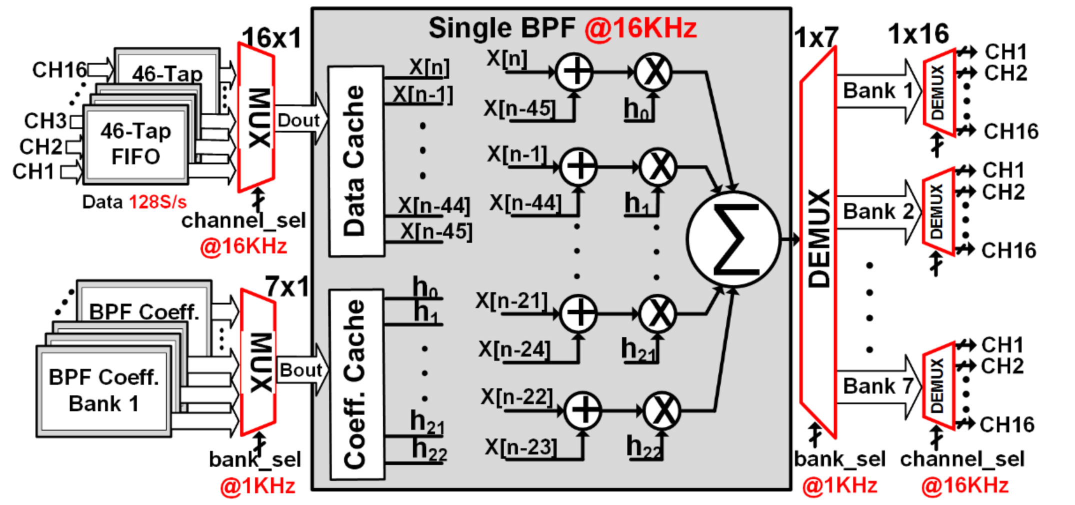
Feature Vector = Spatial + Temporal + Spectral

- 7 BPF*4Hz = 28Hz + Spectral Energy Accumulator(SEA)



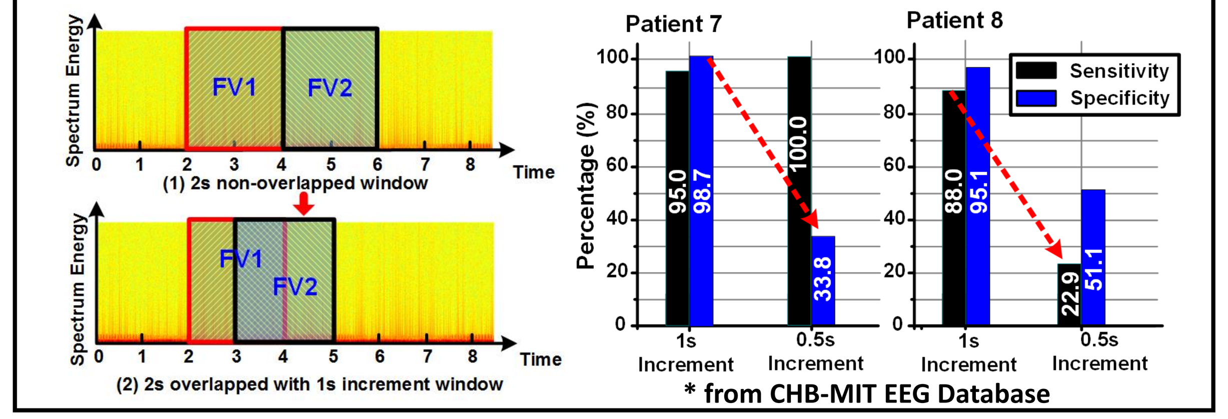
Frequency-Time Division Multiplex BPF Architecture

- 1 BPF for 112 Banks in 16 Channels
- Gates : 40.5%↓ compared to TDM-BPF[5];
- Power: 38.4%↓ compared to TDM-BPF[5];



2s Overlapped-Sliding Window with 1s Increment

- 50% Improvement in System Latency (2s->1s)
- No Compromise in Classification Accuracy



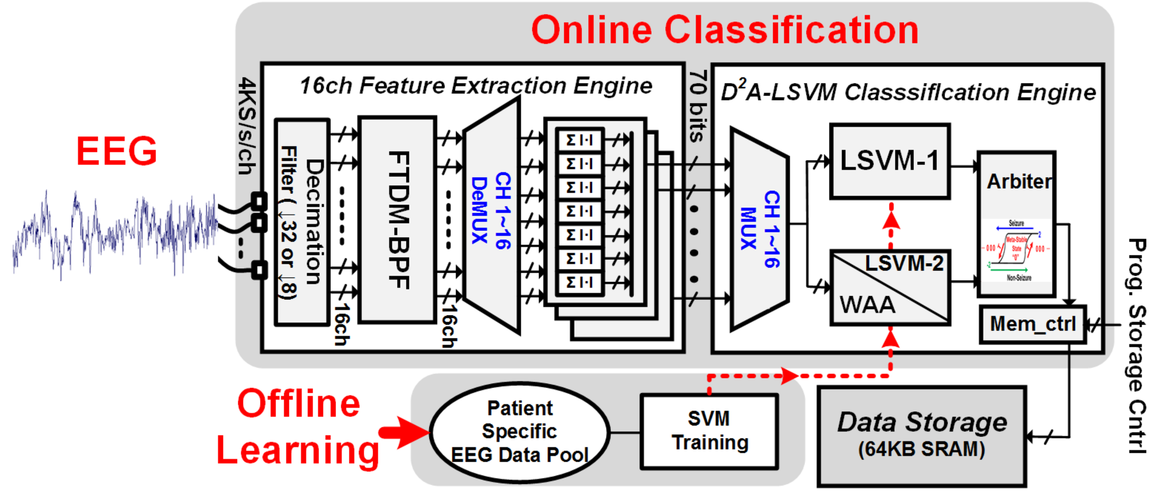
IV. D²A Classification Engine

Conventional SVM-Based Seizure Detector

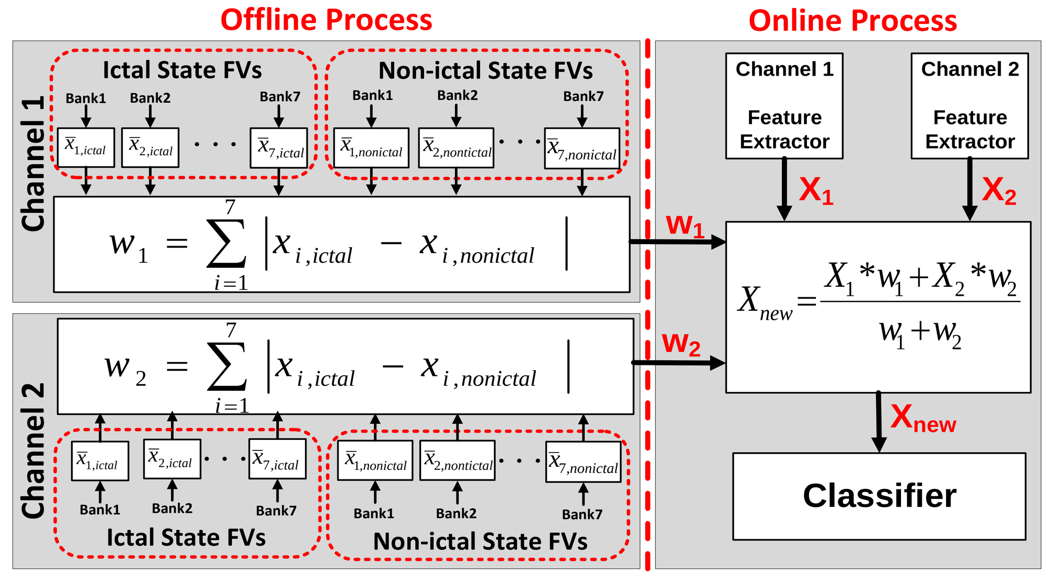
- Single LSVM detector[9] → ☹ Low Accuracy
- Single Non-Linear SVM[11] → ☹ 100's of SVs

Proposed D²A-LSVM Architecture (Two LSVMs)

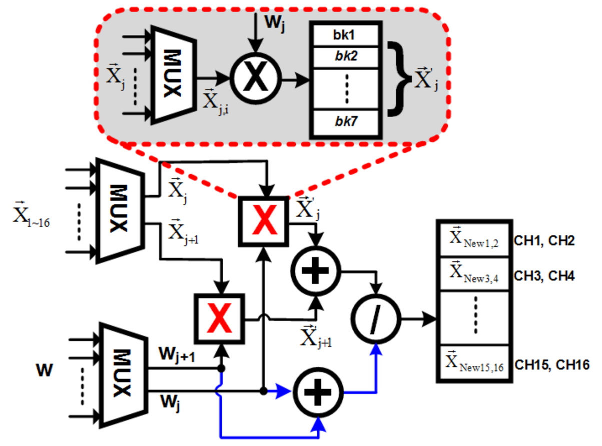
- Detector-1 → Optimized for Sensitivity
- Detector-2 → Optimized for Specificity



a) Weight-And-Average Algorithm



- WAA Implementation using TDM
- Gates: 56.0% ↓
- Power: 27.5% ↓

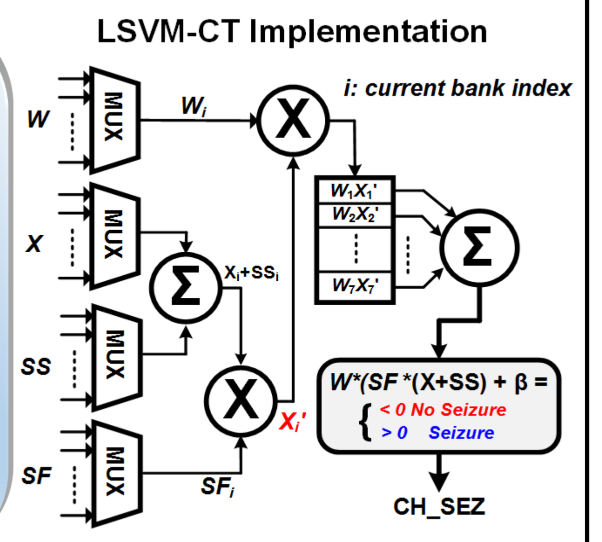


IV. D²A Classification Engine (contd.)

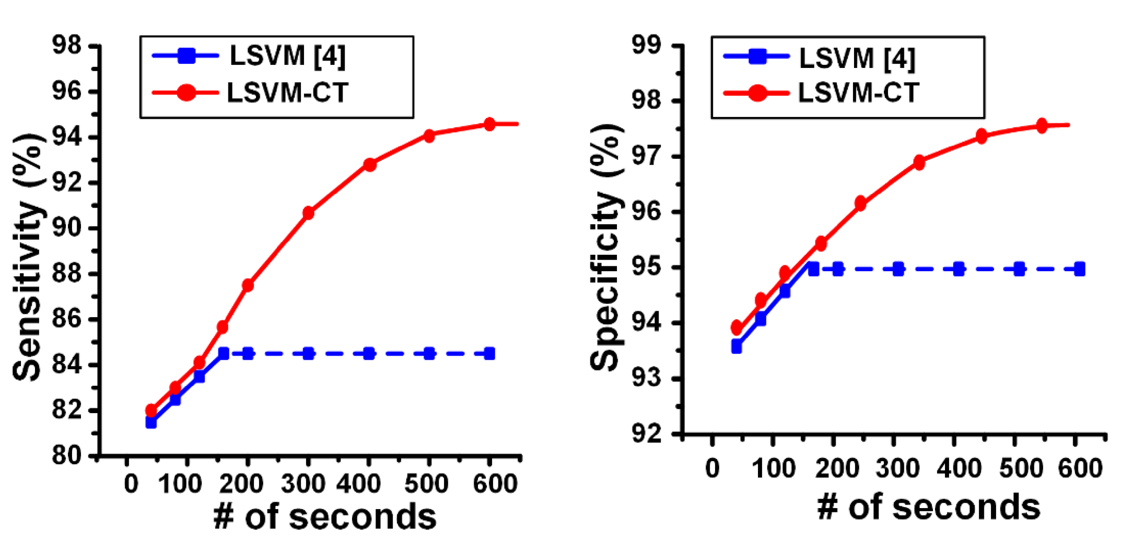
b) Linear SVM with Condensed Training (LSVM-CT)

- More Tolerance Margin
- Data Compression for CT
- Sensitivity: 84.4% → 93.5%
- Specificity: 95.0% → 97.6%

(Results based on Single LSVM-CT)



(a) LSVM-CT vs LSVM

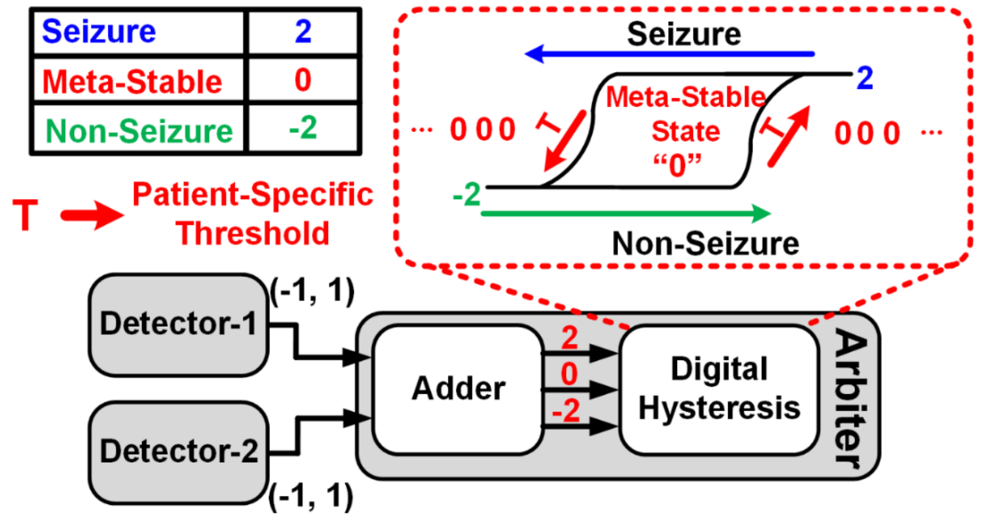


c) Arbiter with Digital Hysteresis

- Combines both detectors' advantages
- Improves Sensitivity and Specificity simultaneously
- Decreases overall false alarms

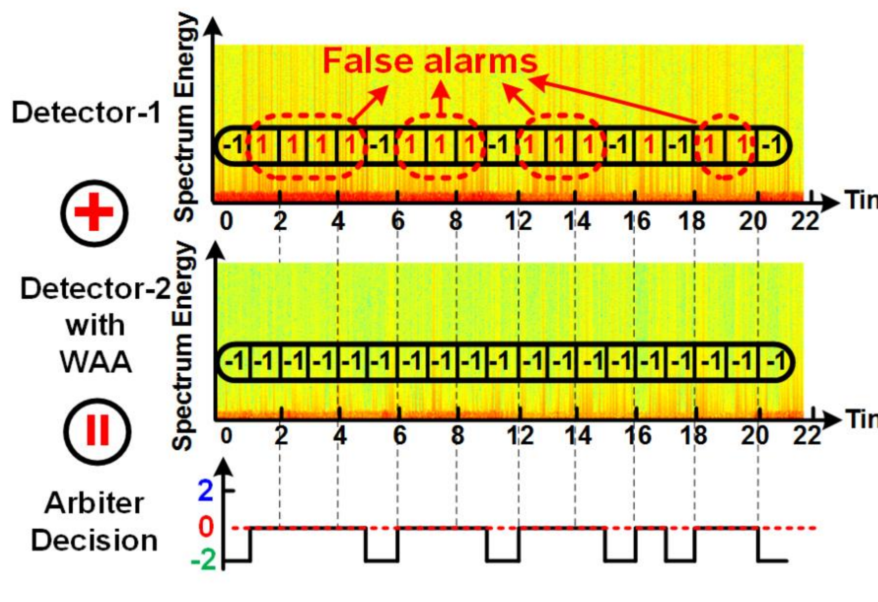
Seizure	2
Meta-Stable	0
Non-Seizure	-2

T → Patient-Specific Threshold

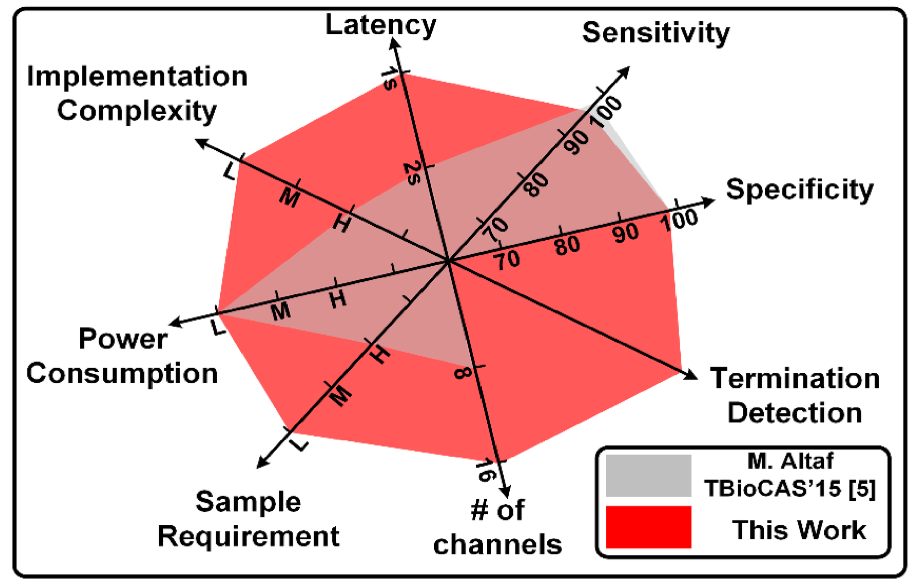


V. Implementation Results

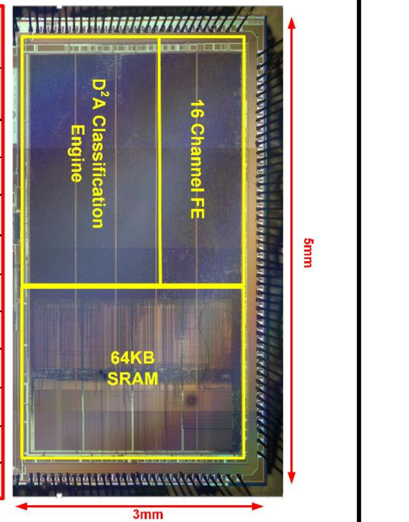
False alarm elimination with digital hysteresis



Seizure detection SoC Comparison



Parameter	JSSC'13 [4]	ISSCC'13 [5]	TBioCAS'13 [6]	JSSC'14 [7]	JSSC'13 [8]	This Work
	Linear SVM	Gaussian SVM	HFD	LLS	SVM	D²A-LSVM
Patient Specific	O	O	O	X	O	O
Seizure Termi. Detection	X	X	X	X	X	O
Sensitivity	84.4%	>96%	100%	92%	100% (by event)	95.7%
Specificity	96%	>99%	100%	--	0.75 FA/H	98.0% (0.27 FA/H)
Onset Delay	--	--	13.8s	--	15s	3.4s
System Latency	2s	2s	--	0.8s	--	1s
No. of Channels	8	8	1	8	1	16
On Chip Storage	O	O	X	X	X	O
Energy Efficiency	1.49uJ/Class	1.31uJ/Class	44.85nW	77.9uJ/Class	273uJ/Class	1.85uJ/Class
Technology	0.18um	0.18um	0.18um	0.18um	0.13um	0.18um



References

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