



DESIGN, AUTOMATION
AND TEST IN EUROPE

THE EUROPEAN EVENT FOR
ELECTRONIC SYSTEM DESIGN & TEST

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CENTRE DE CONGRÈS DE LYON



KalmMind: A Configurable Kalman Filter Design Framework for Embedded Brain-Computer Interfaces

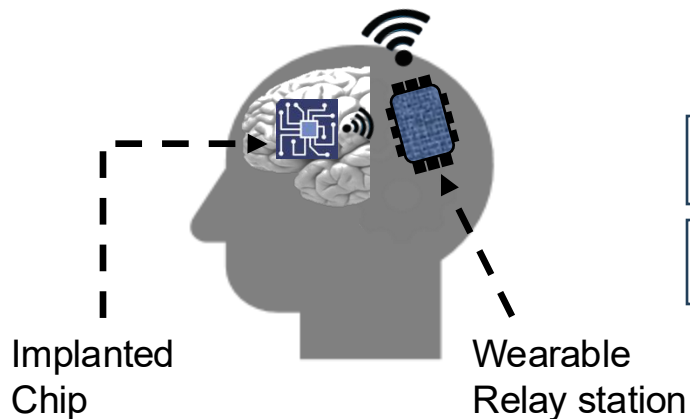
Guy Eichler, Joseph Zuckerman, Luca Carloni
Columbia University



The KalmMind Framework

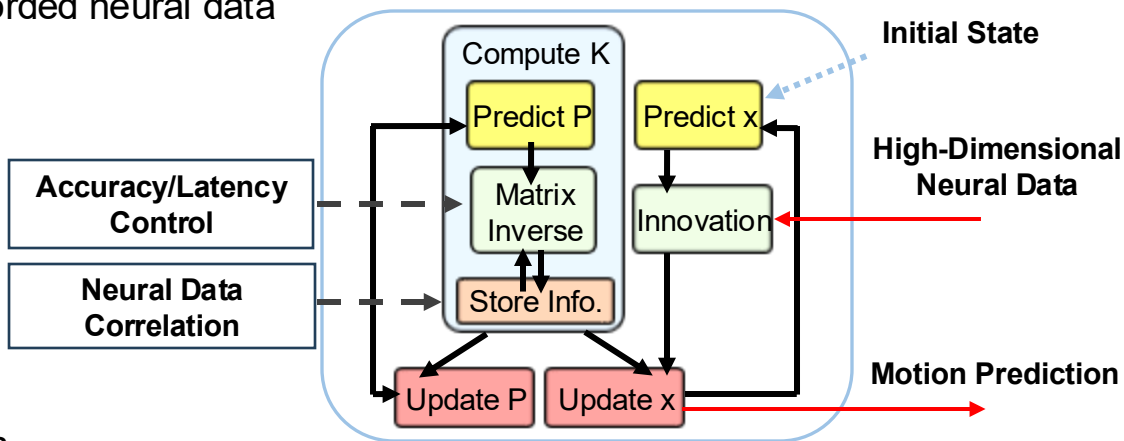
Brain-Computer Interface (BCI):

- **The goal** is to improve quality of life
- **Real-time** computation
- Meet **low-power** constraints
- **Our Focus:** Predicting motion from recorded neural data



Kalman Filter Algorithm:

- **Main bottleneck is the matrix inverse**
- Interleaving approximation and calculation - **Accuracy/Latency Tuning**



Results

- **Gaussian elimination (Gauss)** calculation and **Newton-Raphson (Newton)** approximation
- Hardware accelerator with **Gauss calculation** and **Newton approximation**

Comparison between matrix inverse methods

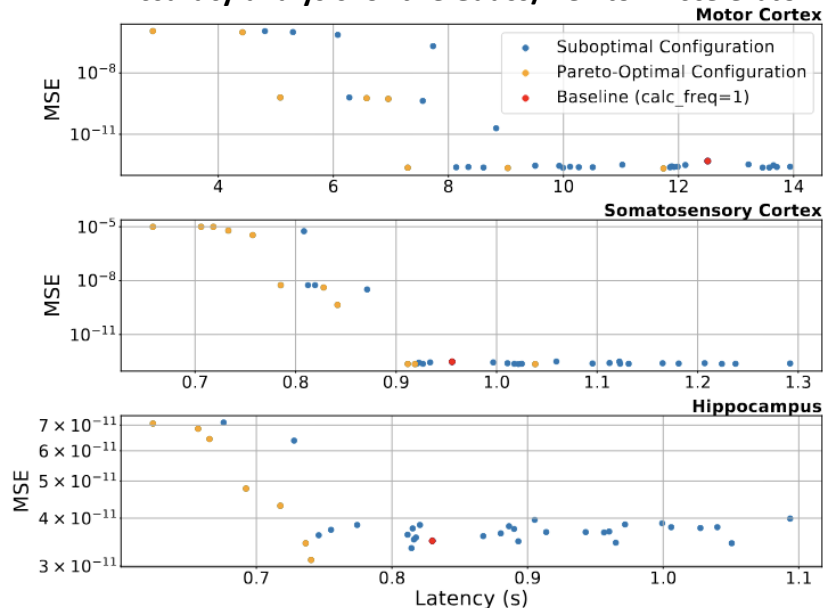
Accuracy Metric	Gauss	Taylor [11]	SSKF [12]	Newton [10]
MSE	3.8×10^{-12}	0.05	0.1	6.6×10^{-6}
MAE	7×10^{-7}	0.08	0.06	0.0004
*Max. Difference (%)	0.008	9.7×10^2	5.3×10^2	4
*Avg. Difference (%)	0.0001	9	4.8	0.035

Accuracy analysis for the Gauss/Newton Accelerator (3 brain datasets)

	MSE	MAE	MAX DIFF
Motor	$2.1 \times 10^{-13} - 1.1 \times 10^{-6}$	$2 \times 10^{-7} - 1.6 \times 10^{-4}$	$4.3 \times 10^{-5} - 1.91$
Soma.	$2.2 \times 10^{-13} - 9.9 \times 10^{-6}$	$2.3 \times 10^{-7} - 5.1 \times 10^{-4}$	$3.5 \times 10^{-5} - 5.3$
Hippo.	$3.1 \times 10^{-11} - 7.1 \times 10^{-11}$	$1.2 \times 10^{-6} - 2.2 \times 10^{-6}$	$8.2 \times 10^{-5} - 2.1 \times 10^{-3}$
Baseline	4.8×10^{-13} , 3×10^{-13} , 3.5×10^{-11}	2.7×10^{-7} , 2.7×10^{-7} , 1.4×10^{-6}	1.1×10^{-4} , 8.5×10^{-5} , 3.8×10^{-4}

- Wide ranges of accuracies for each dataset
- **Better accuracies than the baseline**
- FPGA tests - Up to **55% better accuracy** and **4.4x speedup**

Accuracy analysis for the Gauss/Newton Accelerator



Thank You!

guyeichler@cs.columbia.edu

