MATLAB EXPO

ACCÉLÉRER LE DÉVELOPPEMENT ET LA MISE EN ŒUVRE DE FONCTIONNALITÉS BMS AUTOMOBILES

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CTO Automotive System Innovations

NXP | SECURE CONNECTIONS FOR A SMARTER WORLD

PUBLIC

Accelerating development and implementation of automotive BMS functionalities (e.g. SoC, SoH) on NXP Greenbox 3 with MATLAB and Simulink

Introduction

Data Generation with Simulink BMS model

State-of-Charge Algorithms Investigation

Prototyping on NXP GreenBox with Simulink

Introduction

SECURE CONNECTIONS
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NXP SEMICONDUCTORS: CORPORATE OVERVIEW

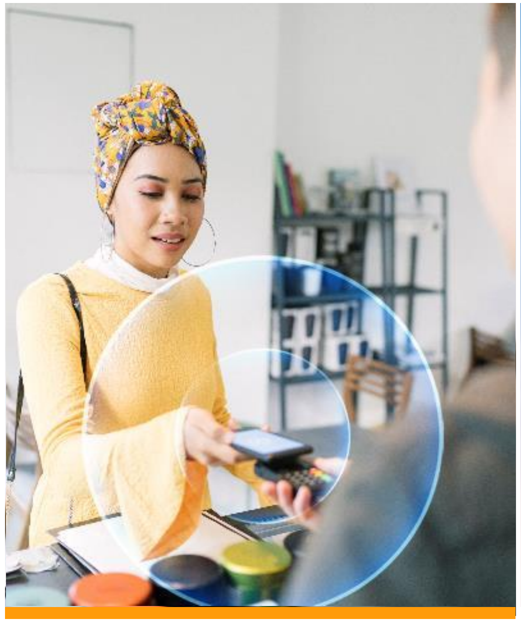
World leader in secure connectivity solutions for embedded applications, NXP is pushing boundaries in the automotive, industrial & IoT, mobile, and communication infrastructure markets.

OUR TARGET MARKETS

AUTOMOTIVE

INDUSTRIAL & IOT

MOBILE



COMMUNICATION INFRASTRUCTURE

A POSITION OF STRENGTH TO BETTER SERVE OUR 26,000+ CUSTOMERS

We accelerate breakthroughs that advance the world through our semiconductor technology leadership

EMPLOYEES IN

30+ COUNTRIES

France: Caen, Paris, Mougins, Toulouse, Grenoble

~34,500

TEAM MEMBERS

France > 1150

9,500

Patent Families

$13.21B

Annual Revenue [1]

60+

Year History

~11,000

Engineers

[1] Posted revenue for 2022 – Please refer to the Financial Information page of the Investor Relations section of our website at www.nxp.com/investor for additional information

GREENBOX 3 DEVELOPMENT PLATFORM FOR S32Z2 AND S32E2 REAL-TIME PROCESSORS

NXP
S32E2-GRNBOX3

www.NXP.Com/GreenBox3

Main Function

- Quick evaluation for Hybrid & Electric Vehicle propulsion, motor-control and battery management use cases
- Complete NXP system solution includes PMICs, Ethernet switch & CAN transceivers

S32Z2/E2

- ASIL D
- 8x Arm Cortex-R52 cores operating up to 1 GHz with NEON™, powerful support for distributed computing, machine learning workloads and DSP/ML Processor offload
- Numerous automotive communication interfaces: Ethernet, CAN FD, LIN, UART, JTAG, SDHC, PSI5, SENT
- Easy to use out of the box experience with advanced control applications including example code

Compatible with S32Z/E Vehicle Integration Platform (GreenVIP)

- Provide a functional software platform that allows customers to begin developing an application on the S32ESZ family with minimal effort

AUTOMOTIVE BATTERY MANAGEMENT SYSTEM (BMS)

- Megatrend: electrification of vehicles
- Typical number of cells in a car battery pack: between **100** and **200**
- Cells are monitored continuously (current, voltage, temperature)
- **BMS** purposes: avoids hazards, optimizes charging and discharging
- Today, BMS processing mostly based on signal processing techniques

Challenge

Accurate estimation of the **State-of-Charge (SoC)** of the battery cells required

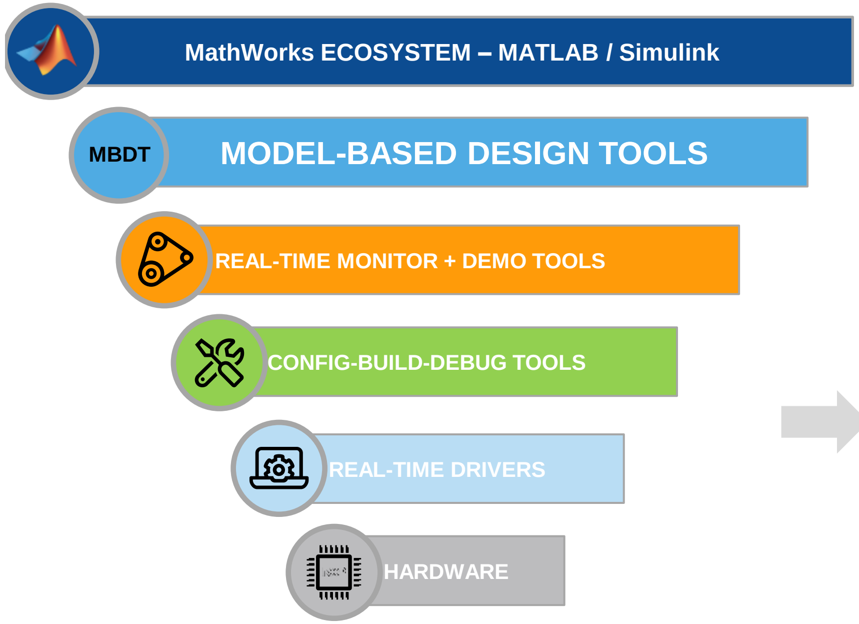
→ Can we do it with **Deep Learning**?

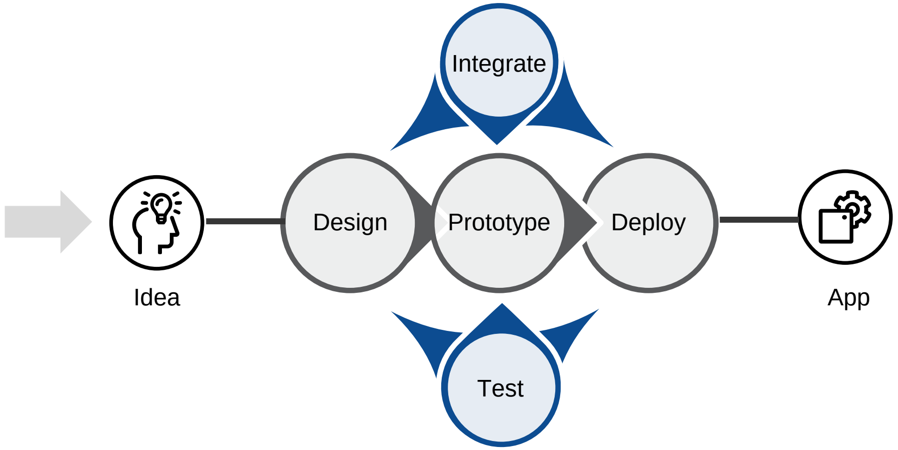
MODEL-BASED DESIGN TOOLBOX (MBDT)
ADVANCED TOOLING ADD-ON FOR MATLAB® AND SIMULINK®

Developed as collaboration between NXP and MathWorks. MathWorks tools optimized for use with NXP HW.

"A collection of Tools & Libraries designed to assist customers with prototyping and accelerate algorithm development on NXP MCUs from MATLAB and Simulink"

- Provides an **integrated development environment** and **toolchain support**
- Used to **configure**, **generate** and **deploy** applications on the MCU
- "True" Model-Based Design approach by introducing the usage of an **External Configuration tool** for **pins, clocks and peripherals**
- Generates code on top of NXP's **Real-Time Drivers** (RTD) for AUTOSAR® and non-AUTOSAR





Data Generation with Simulink BMS model

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DATA GENERATION – BMS SIMULINK MODEL (1)

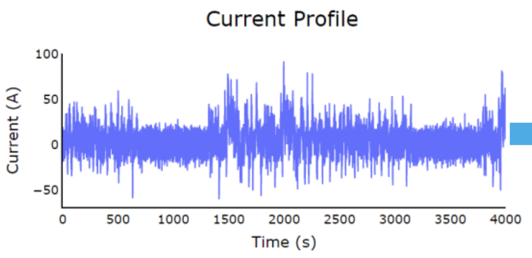
- Very few public datasets available
- Data generation based on [MathWorks BMS Simulink model] + light customization (thermal etc.)

  → 6 or 16x6 cells in series

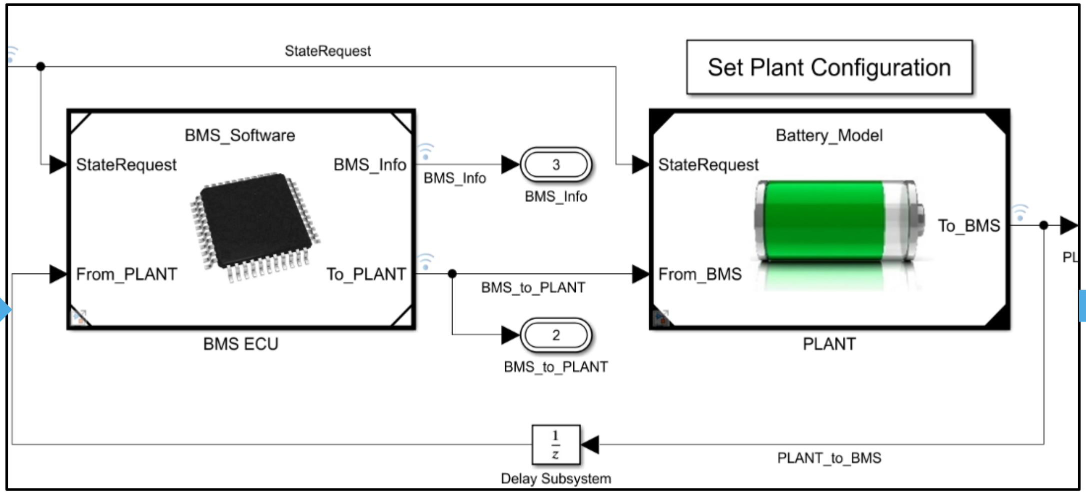
Development of 54 profiles:
- *48 for training*
- *6 for validation/test*

- Current (of the pack)
- Temperature
- Voltage
- “True” SOC
- SOC calculated with Coulomb Counting and EKF

→ ***per cell***



Input current profile



Simulink BMS model

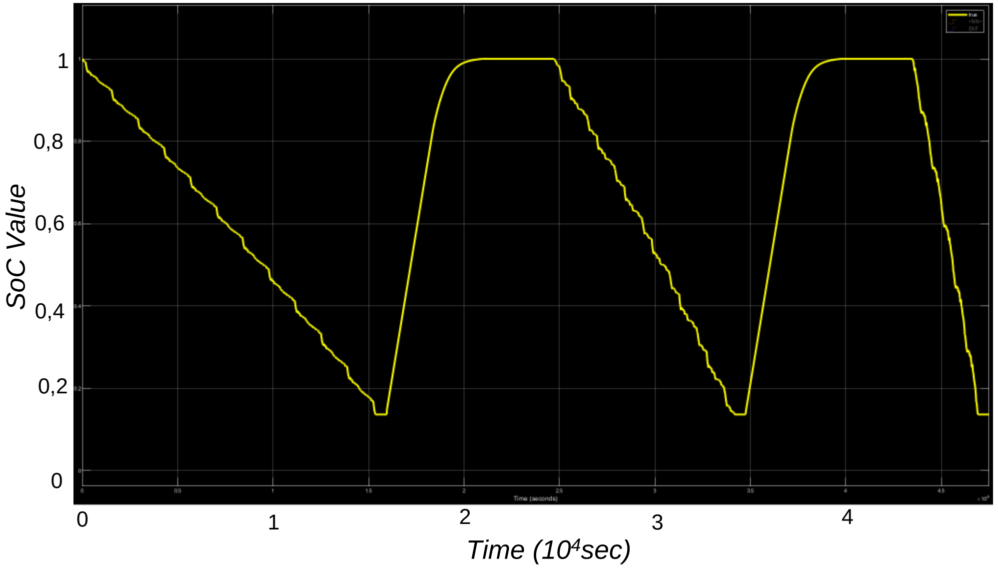
	Time	<BMS_State>	SOC_CC	SOC3_UKF	SOC2_EKF	TrueSOC5	...	Temp_cell_5	Cell_voltage_6
0	0.0	BMS_Standby	0.567099	0.617106	0.617108	0.567099	...	288.1500	3.705930
1	0.1	BMS_Standby	0.567099	0.617105	0.617107	0.567098	...	288.1500	3.712385
2	0.2	BMS_Standby	0.567097	0.617102	0.617102	0.567098	...	288.1500	3.727258
3	0.3	BMS_Standby	0.567096	0.617100	0.617100	0.567097	...	288.1500	3.715454
4	0.4	BMS_Standby	0.567096	0.617098	0.617097	0.567097	...	288.1500	3.725382
...	...	...	...	...	...	...	...	...	...
141419	14141.9	BMS_Charging	0.949902	0.952363	0.953325	0.950048	...	314.6886	4.204524
141420	14142.0	BMS_Charging	0.949908	0.952473	0.953628	0.950055	...	314.6881	4.204523
141421	14142.1	BMS_Charging	0.949915	0.952530	0.953781	0.950062	...	314.6876	4.204523
141422	14142.2	BMS_Charging	0.949922	0.952475	0.953608	0.950069	...	314.6871	4.204522
141423	14142.3	BMS_Charging	0.949929	0.952423	0.953447	0.950075	...	314.6866	4.204521

141424 rows × 41 columns

Generated data

DATA GENERATION – BMS SIMULINK MODEL (2)

Example of charge/discharge cycle



Model architecture of the cells

Ambient temperature

Cell 6

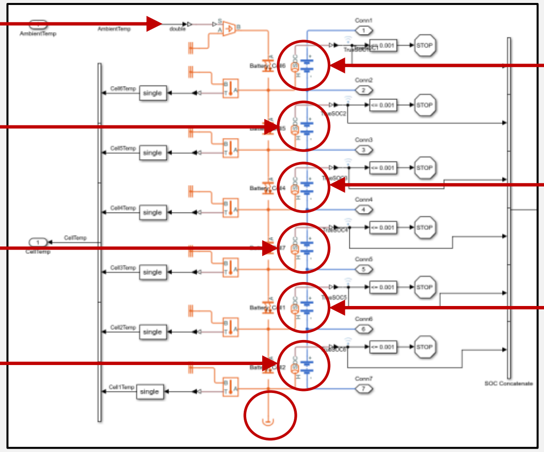
Cell 5

Cell 4

Cell 3

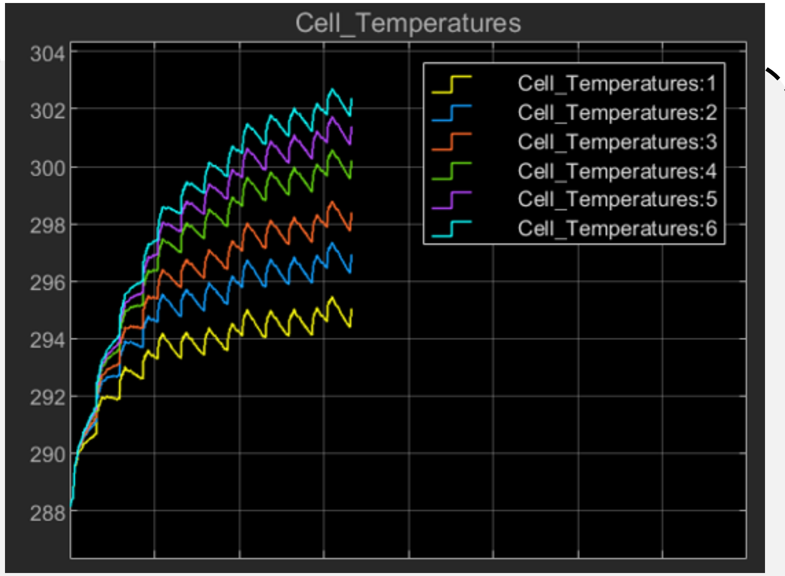
Cell 2

Cell 1



Module of 6 cells in series

different temperature evolutions
due to different thermal dissipation



Cell temperature

SoC Algorithms Investigation

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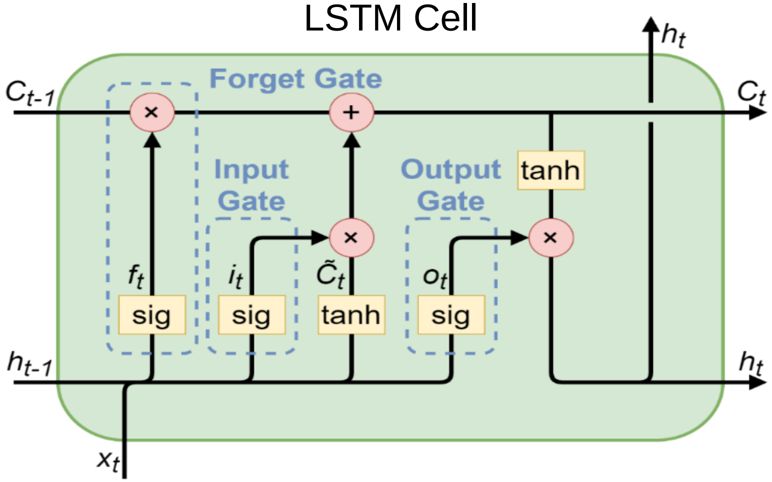
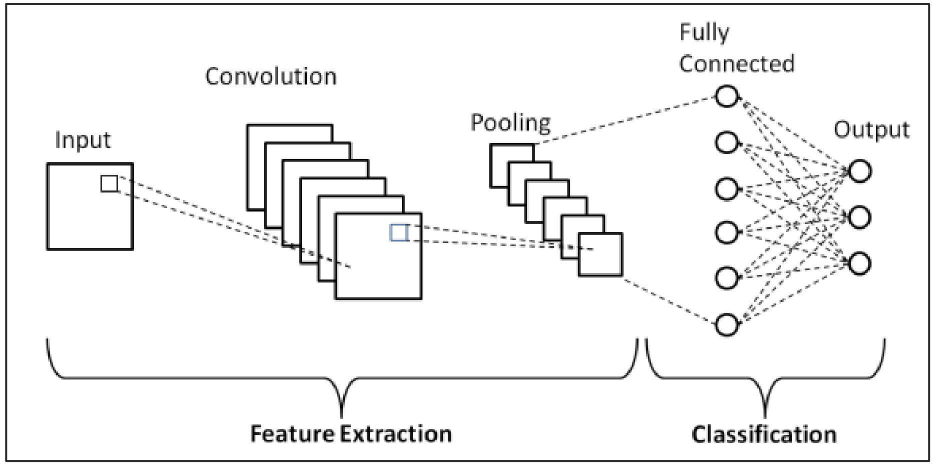
ALGORITHMS INVESTIGATION

- Investigate the **features**
- Investigate the **input shape**
- Investigate the neural network architecture: **recurrent** VS **convolutional**
- Investigate the **hyperparameters**

LSTM Cell

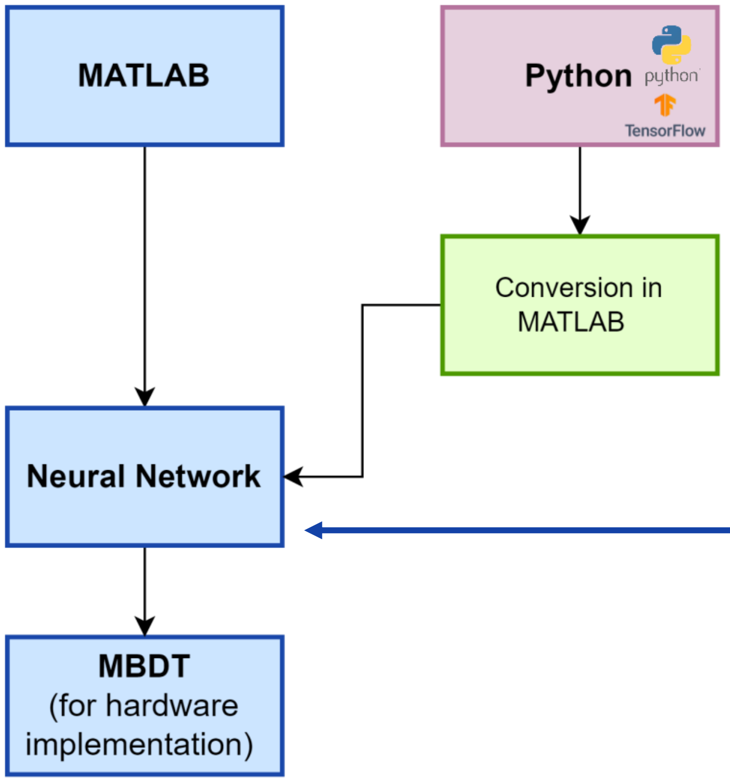


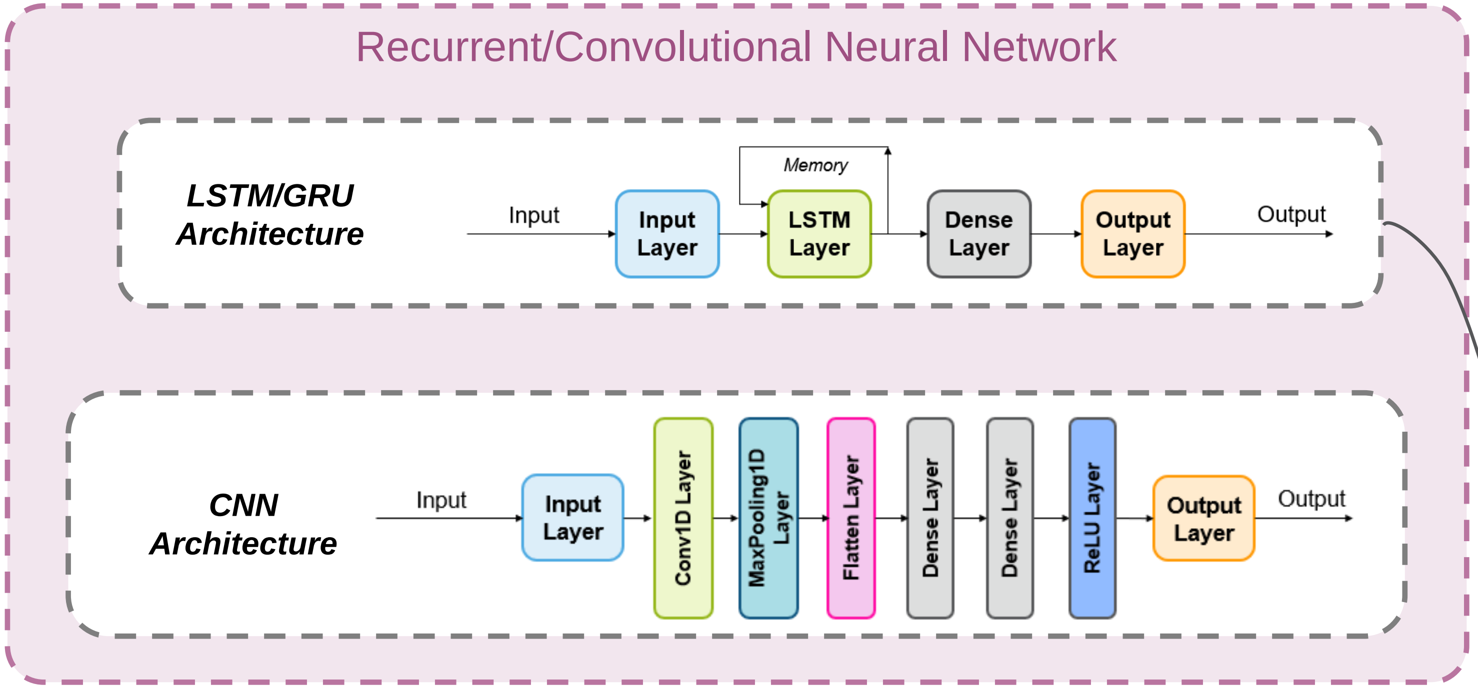
CNN

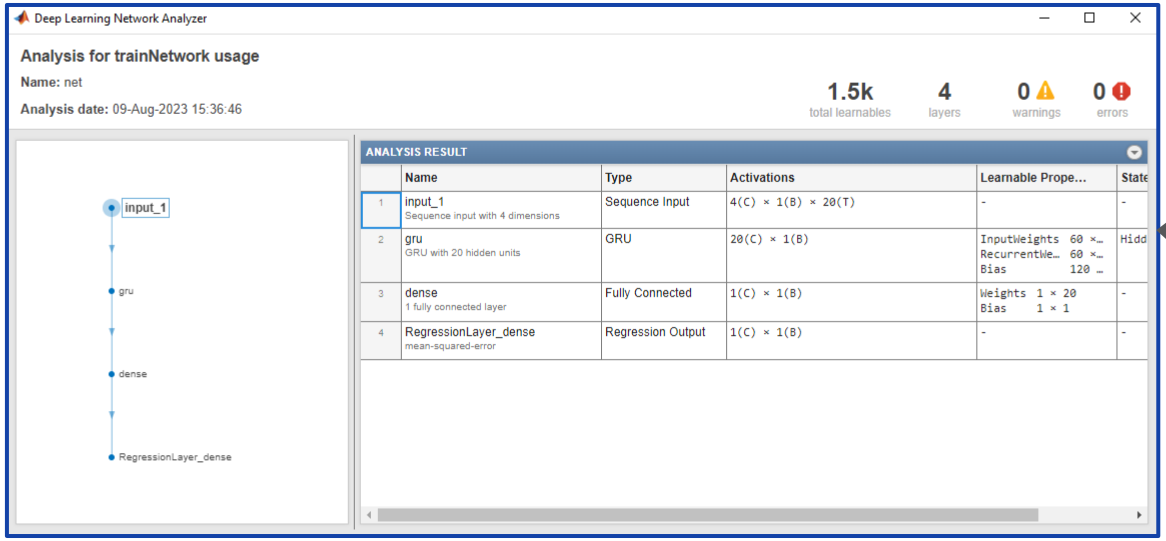


ALGORITHMS INVESTIGATION

Flexibility in the workflow







MATLAB Deep Learning Network Analyzer

Prototyping on NXP GreenBox with Simulink

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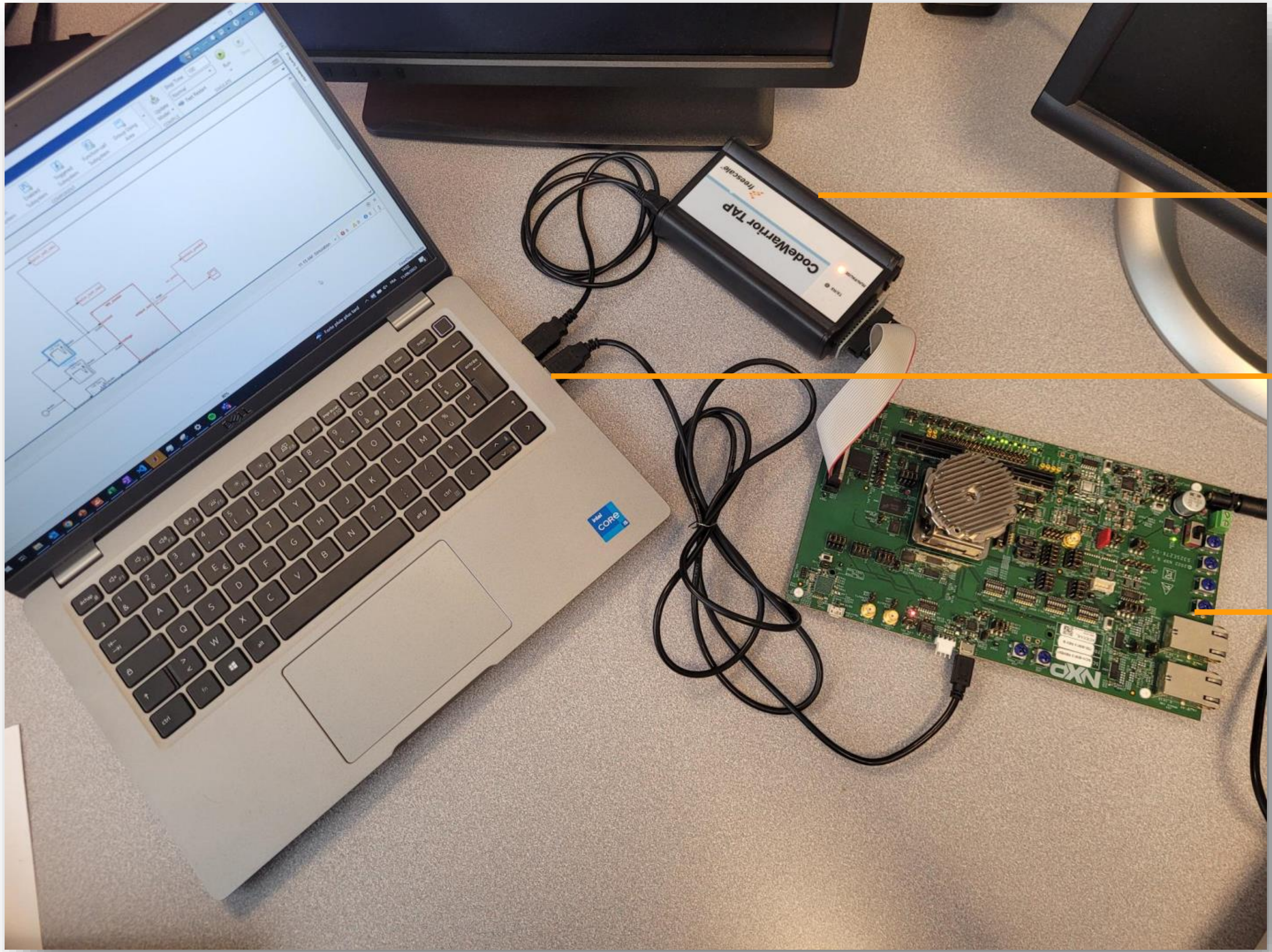
SETUP

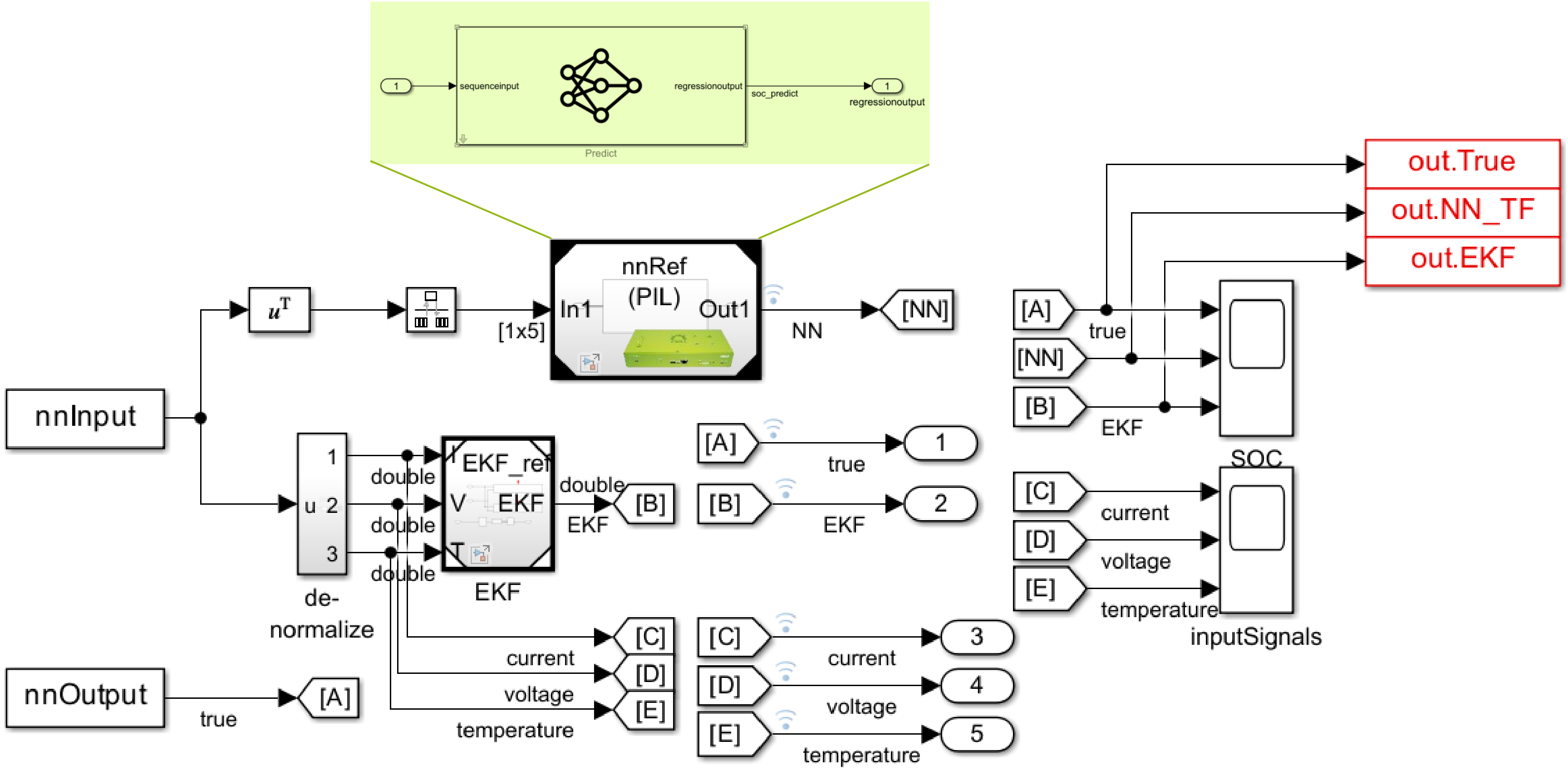


CodeWarrior Debug Probe

Computer with Simulink and Serial connection

GreenBox 3 Daughter Card with S32E278 Processor

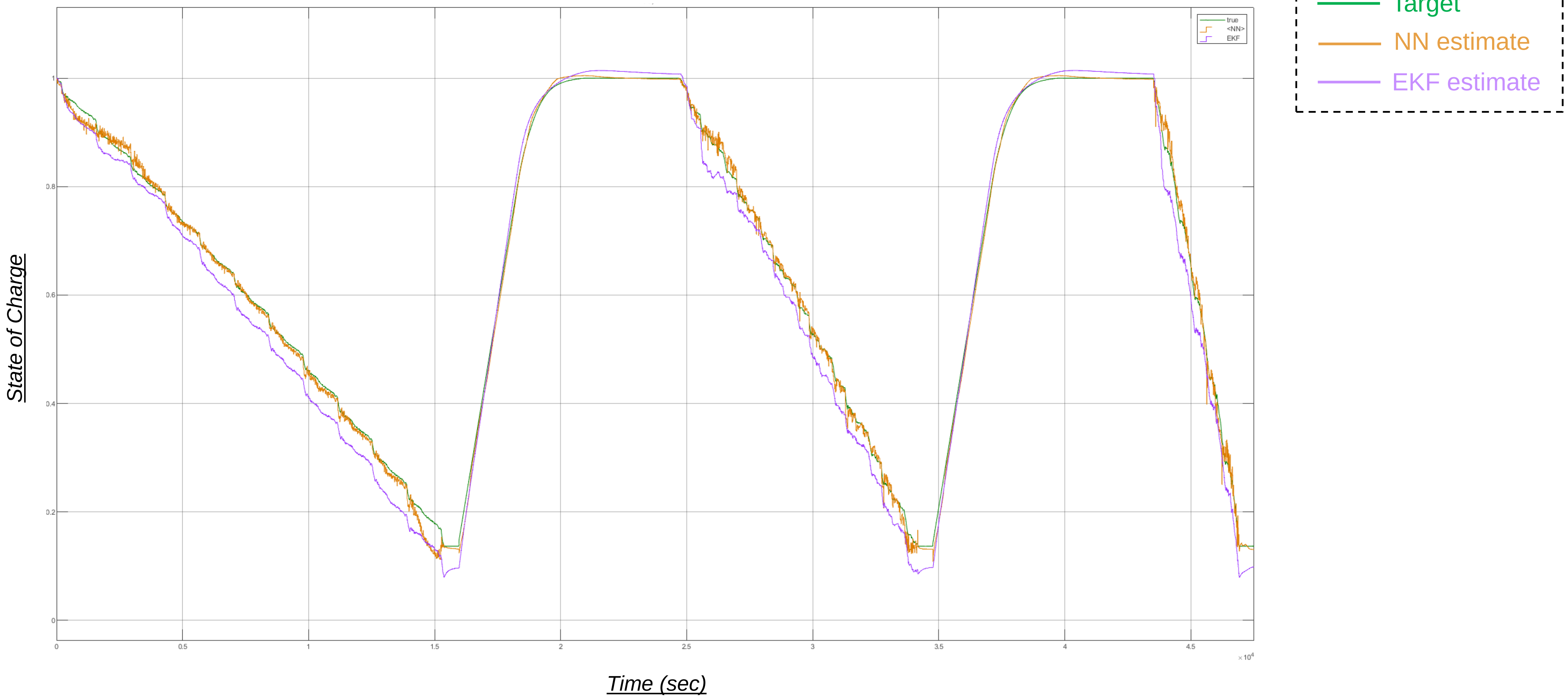
- Goal: assess if the ML based SoC algorithm can be run on embedded platform
- Use of the **Model-Based Design ToolBox** in Simulink to generate C code and run it on **NXP GreenBox**
- Adapt the models developed in Python environment to MATLAB



Simulink Model

PROTOTYPING – SIMULINK MODEL (2)

SoC according to estimation method EKF/FNN



PROTOTYPING – SIMULINK MODEL (3)

- The MBDT provides a Profiling Report
- Example generation of the profiling report for one sequence data (3*70) as input for LSTM model

Code Execution Profiling Report for NN_SoC_predict_App

The code execution profiling report provides metrics based on data collected from a SIL or PIL execution. Execution times are calculated from data recorded by instrumentation probes added to the SIL or PIL test harness or inside the code generated for each component. See Code Execution Profiling for more information.

1. Summary

Total time	119862
Unit of time	ns
Command	report(, 'Units', 'seconds', 'ScaleFactor', '1e-09', 'NumericFormat', '%0.0f');
Timer frequency (ticks per second)	8e+08
Profiling data created	02-Aug-2023 16:35:16

2. Feasibility Checks [hide]

Check Description	Results
Overall average CPU utilization lower than threshold (70%)	Passed
Overall maximum CPU utilization lower than threshold (70%)	Passed
All average execution times are shorter than their task period	Passed
All maximum execution times are shorter than their task period	Passed

3. Profiled Sections of Code

Section	Maximum Execution Time in ns	Average Execution Time in ns	Maximum Self Time in ns	Average Self Time in ns	Calls
[+] NN_SoC_predict_App_initialize	292	292	292	292	1
[-] NN_SoC_predict_App_step [0.1 0]	85696	1683	276	101	71
From Workspace6	532	386	532	386	71
[-] Neural network	84887	84887	184	184	1
[-] DeepLearningNetwork_predictAndU	84704	84704	6902	6902	1
[+] NN_model_matrixMultiply1	10702	10702	698	698	1
[+] NN_model_matrixMultiply1	27289	27289	560	560	1
exp	488	446	488	446	30
[+] NN_model_matrixMultiply1	3801	3801	529	529	1
[+] NN_model_matrixMultiply1	9474	9474	520	520	1
tanh	842	741	842	741	10
tanh	624	574	624	574	10
[+] NN_SoC_predict_App_terminate	77	77	77	77	1

Execution Profile given by the MBDT

0,12 ms

Total execution time

Take aways

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CONCLUSIONS

Data Generation

- ✓ Able to generate meaningful datasets with Simulink model

Algorithm investigation

- ✓ Able to explore variety of SoC algorithms with MATLAB/Simulink toolboxes
- ✓ AI-based SoC algorithms (FNN, LSTM…) show equal or better accuracy than ‘classical’ EKF
- ✓ Bridges with Python environments

Prototyping

- ✓ C code generation from Simulink
- ✓ Fast prototyping
- ✓ Detailed performance report

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