



# Onboard Battery Pack State of Charge Estimation Using a Neural Network

MathWorks AUTOMOTIVE CONFERENCE 2022

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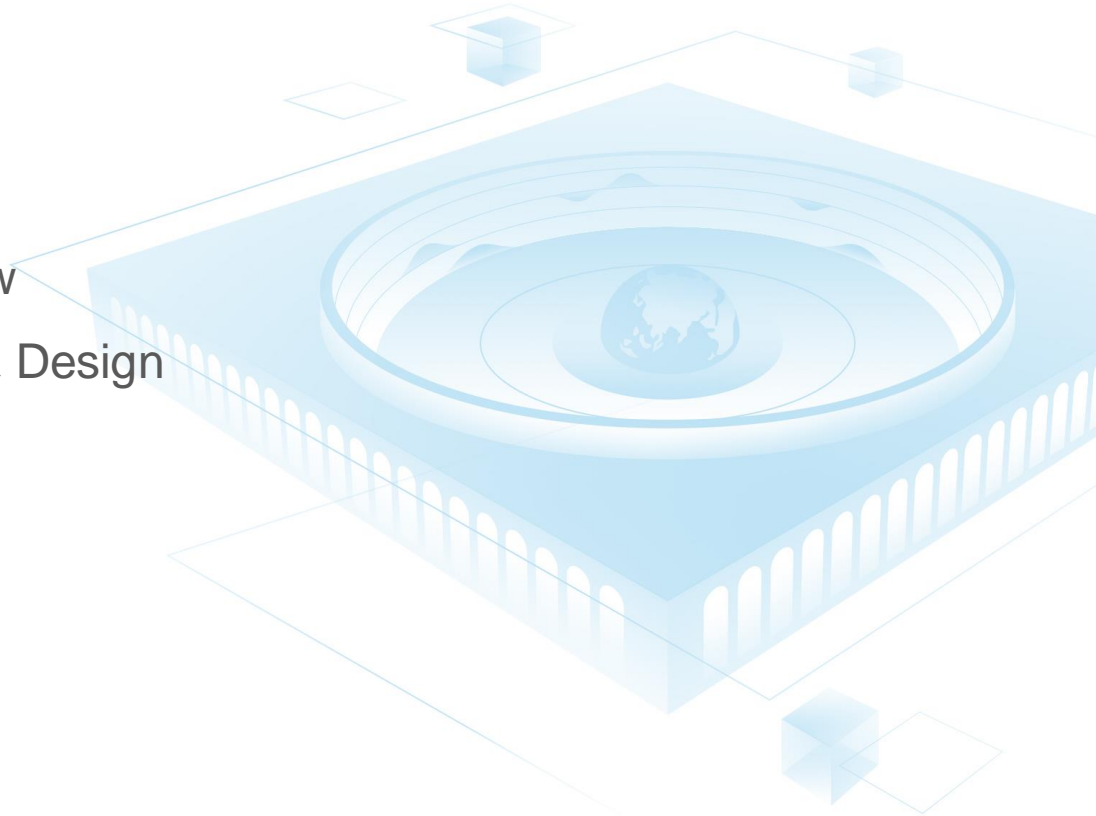
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# CONTENTS

- Prototype Project Overview
- Prototype Requirements & Design
- Prototype Tests
- Summary



# Prototype Project Overview

## SOC Estimation Prototype:

- Accurate to within 3%
- Target for BMS charging, then to more scenarios
- Deployed as a “shadow” strategy on test vehicles
- Developed using MathWorks tools

## Project Objectives:

- Feasibility assessment
- Design information



Gotion Battery Cells

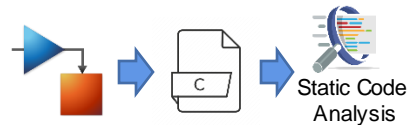
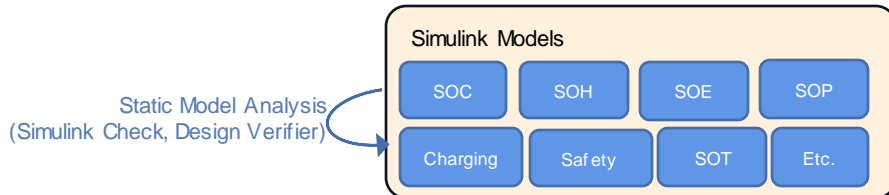
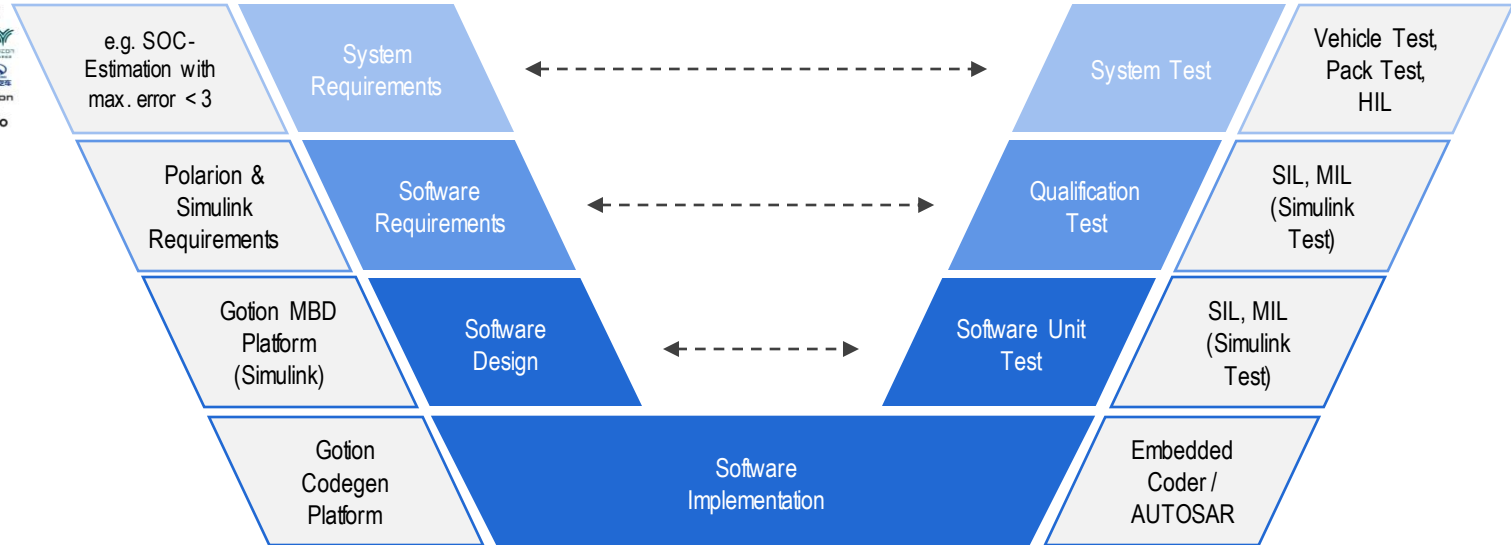


Gotion Battery Pack



DC Charging

# Prototype Project Stages



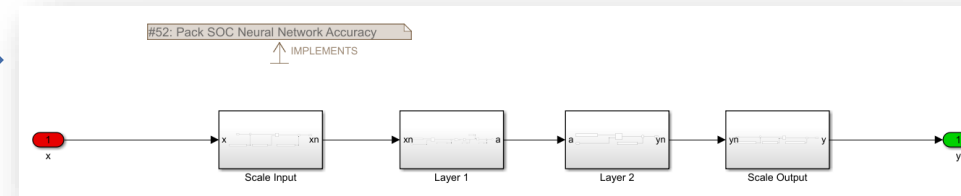
# Prototype Requirements



State	ID	Summary	Implemented	Verified
1	#47	Prototype Pack SOC	Yes	Yes
1.1	#48	Pack SOC Increment Using Coulomb Counting	Yes	Yes
1.2	#49	Voltage-Based Pack SOC Estimate (Charging Only)	Yes	Yes
1.2.1	#52	Pack SOC Neural Network Accuracy	Yes	Yes
1.2.2	#53	Voltage-Based Pack SOC Taming	Yes	Yes
1.3	#50	Final Pack SOC Control	Yes	Yes
2	#54	Prototype Has No Impact on Baseline BMS Behavior	Yes	Yes

**3% Accuracy While Charging**

Requirements Traceability Matrix

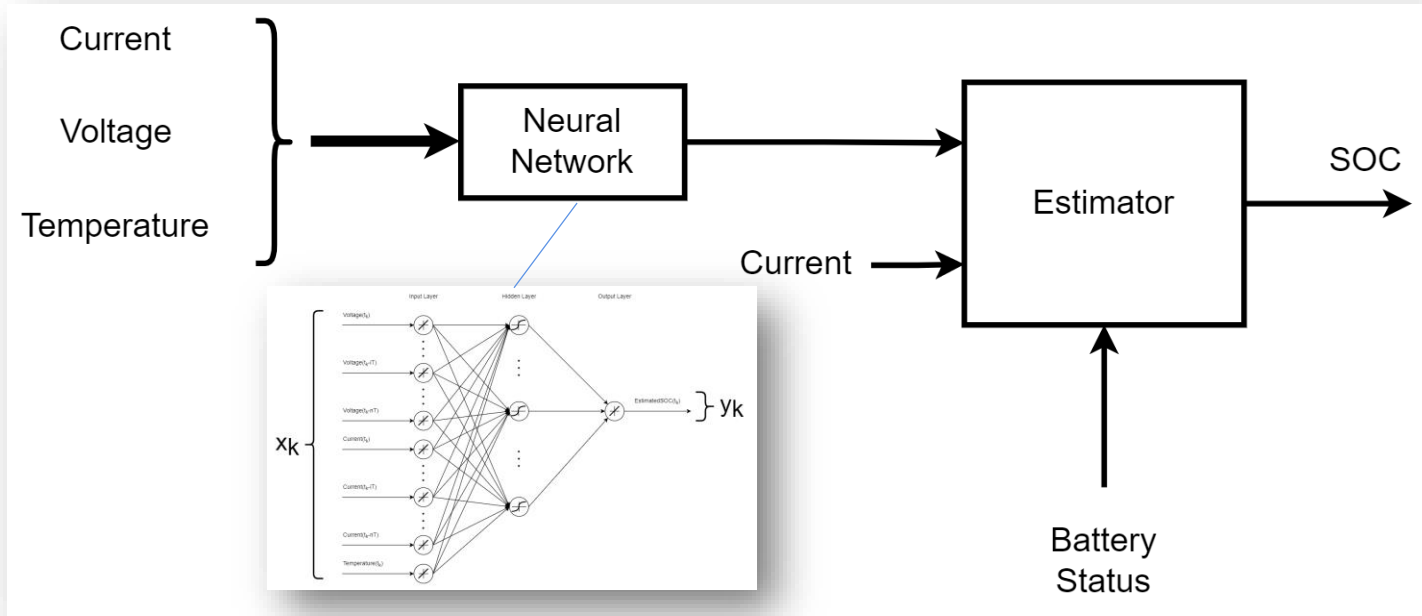


Simulink Model Subsystem

Requirements Editor



# Prototype Design Overview





# Neural Network Training Procedure

Start

Inspect Data

Prepare Input and Target Data

Train Neural Network

Review Fit

Generate m-Code

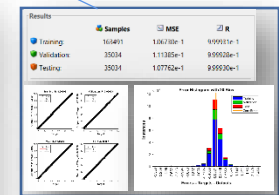
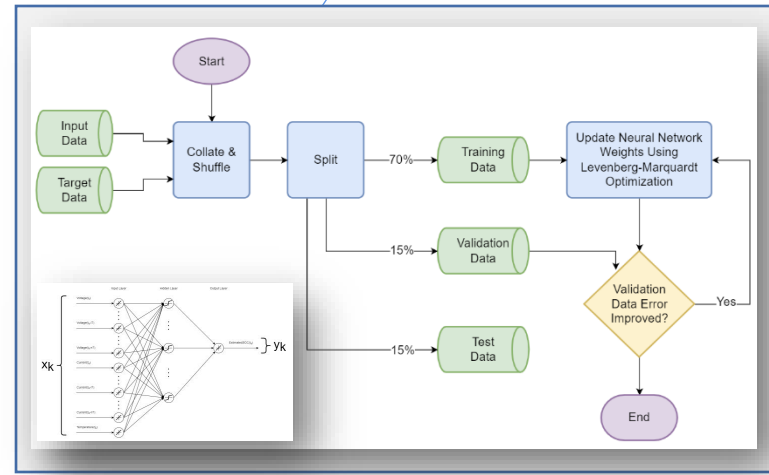
End

97327	97328	97329	97330	97331	97332
4.07160	4.07160	4.07160	4.07170	4.07170	4.07170
4.07000	4.07000	4.07050	4.07100	4.07110	4.07110
4.09970	4.09975	4.09980	4.09980	4.09980	4.09885
-27.50000	-27.50000	-27.50000	-27.50000	-27.50000	-27.50000
-27.50000	-27.50000	-27.50000	-27.50000	-27.50000	-27.50000
-27.50000	-27.50000	-27.50000	-27.50000	-27.50000	-27.50000

**Inputs**

97327	97328	97329	97330	97331	97332
81.54271	81.55855	81.56944	81.58377	81.5983	81.61112

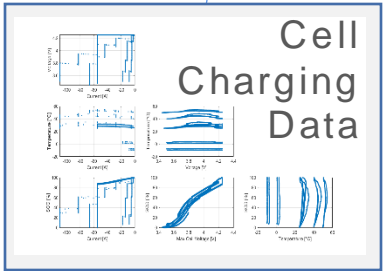
**Targets**



```

1 function [h] = fit_nn(x)
2
3 % NEURAL NETWORK FITTING APP
4 % ----- NEURAL NETWORK CONSTANTS -----
5 % Input 1
6 h1_step = 0.1; % Learning rate
7 h1_hidden = 10; % Number of hidden nodes
8 h1_output = 1; % Number of output nodes
9
10 % Layer 1
11 h1 = [-0.20124215145737880811-1.793987133202032-0.747464848232444641210774842449202-18.2648230
12 % h1 = [-0.20124215145737880811-1.793987133202032-0.747464848232444641210774842449202-18.2648230
13 % h1 = [-0.20124215145737880811-1.793987133202032-0.747464848232444641210774842449202-18.2648230
14
15 % Layer 2
16 h2 = 20.89889898478466472;
17 % h2 = 20.89889898478466472;
18 % h2 = 20.89889898478466472;
19
20 % Output 1
21 h_output = h1;
22
23 end
  
```

**m-Code**



Neural Network Fitting App



# Unit Test: Neural Network Accuracy

Test Harness

Test Manager  
(Simulink Test)

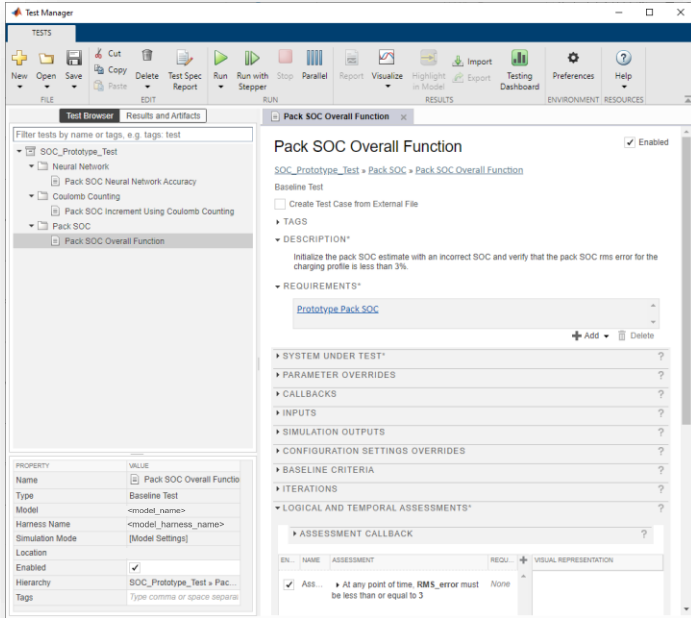
Test Assessment  
Logic



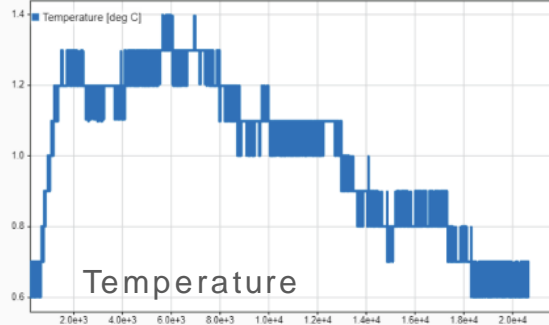
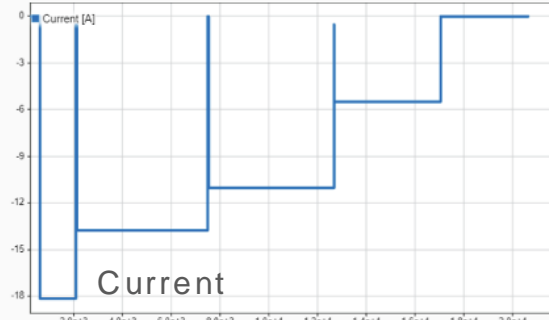
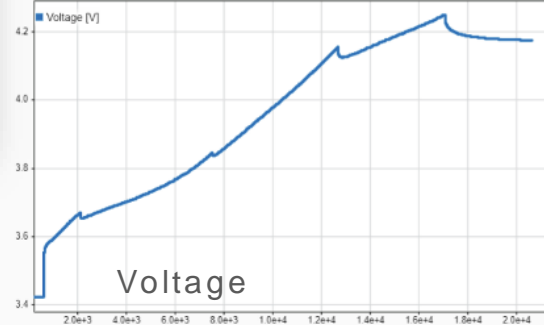
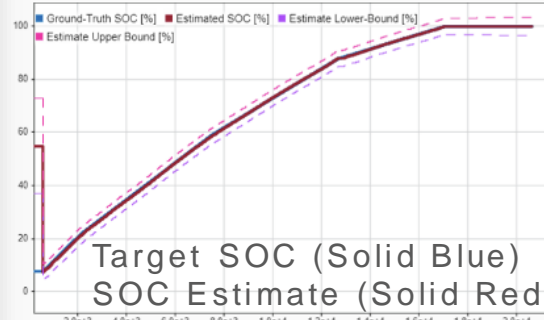


# Qualification Test: SOC Estimation

In spec when tested on *cell charging data*:  
0.5% RMS SOC error when charging, including under cold weather conditions

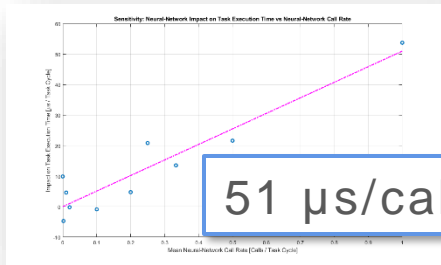
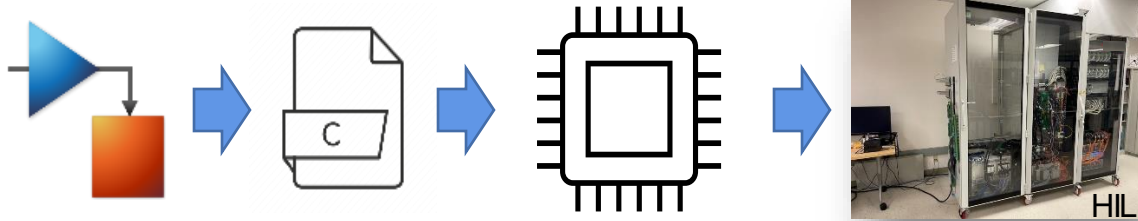


Test Manager  
(Simulink Test)





# System Test on HIL



ANN Execution  
Time

< 2 kB ROM  
< 100 B RAM

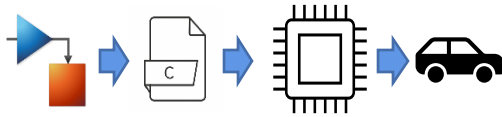
ANN Memory  
Usage

1.98e-04  
Mean Absolute Error

Numerical Equivalence  
(Windows ⇔ Microcontroller)

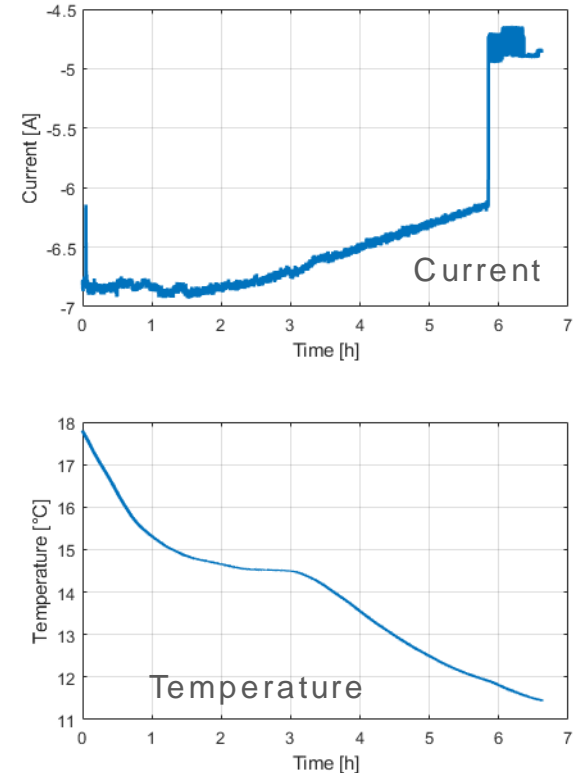
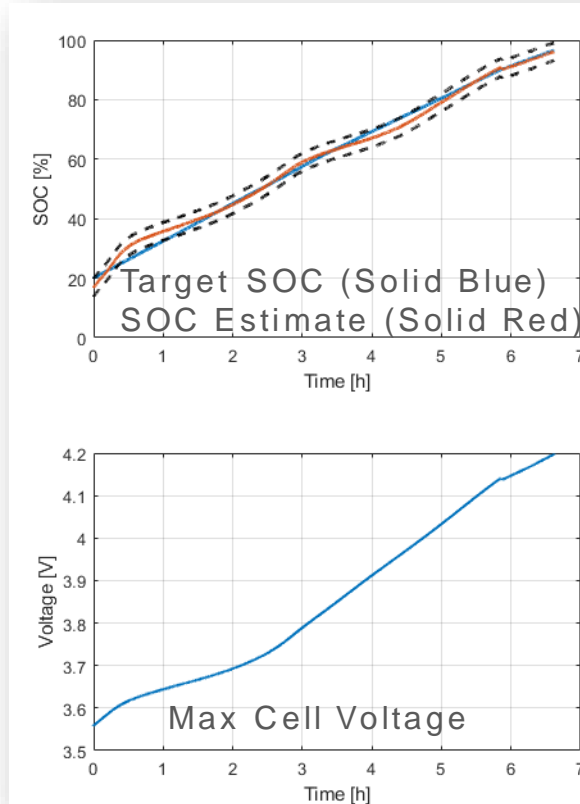


# Onboard Vehicle Test



In spec for  
*onboard vehicle*  
*AC charging tests:*

2% RMS SOC  
error when  
charging



# Summary

Topic	Finding
Algorithm	Onboard SOC estimation w/ ANN
ANN Memory	< 2 kB ROM, < 100 B RAM
ANN Execution Time	~ 50 $\mu$ s/call
Numerical Equivalence (Windows $\leftrightarrow$ Microcontroller)	~ 2e-04 MAE
Sustainable Workflow?	Yes
Onboard Accuracy	< 3% while charging
<b>Feasible?</b>	<b>Yes</b>

MathWorks products discussed:

- Simulink Requirements
- Deep Learning Toolbox
- Simulink
- Simulink Test
- Embedded Coder

