Advanced Capabilities for Embedding Machine Learning into ECUs

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MathWorks
AUTOMOTIVE CONFERENCE 2020
BMW designs, tests and deploys data-driven systems that enhance vehicles’ capabilities with MATLAB & Simulink


> 95% accuracy
MathWorks provides tools to design and verify smart, data-driven machine learning systems

\[
f(x) = y
\]

\[
\hat{f}(x_{\text{train}}) = y_{\text{train}}
\]

\[
\hat{f}(x_{\text{new}}) = \hat{y}
\]
MathWorks provides embedded machine learning workflows that integrate nicely with Model-Based Design.

Embedded Machine Learning
- Data-driven, smart algorithms capable of running on edge devices
Machine Learning algorithms are supported for a variety of embedded systems workflows

**Deploy machine learning models in MATLAB & Simulink**

**Deploy reduced precision machine learning models**

**In-place modification of deployed models**

\[ \text{fixt}(1,8,3) \]

1 0 1 1 0 0 1 0

Real world value: -9.75
Learner Apps provide convenient ways to compare and iterate over different machine learning algorithms.
Classification learner App demonstration
Model trained using Learner App can be saved for deployment

```matlab
ensembleModel = 
    struct with fields:
    .predictFcn: @(...)
    .exportableModel = predictorExtractionFcn(x)
    .ClassificationEnsemble: [1x1 classreg.learning.classif.CompactClassificationEnsemble]
    .HyperParameterOptimizationResult: [1x1 BayesianOptimization]

    About: 'This struct is a trained model exported from Classification Learner R2020a.'
    HowToPredict: 'To make predictions on a new predictor column matrix, X, use: yfit = c.predictFcn(X)'
```

```
saveLearnerForCoder(ensembleModel.ClassificationEnsemble, 'DigitImagesRF');
```
Saved models can be used in Simulink models

openExample('stats/SystemObjectsForClassificationAndCodeGenerationExample')
Saved models can be used in Simulink models

ECOC subsystem

Random forest subsystem

ECOC System object

Random Forest System object
Saved models can be used in Simulink models via System Blocks

classdef RFClassifier < matlab.System
    % RFCLASSIFIER Predict image labels from trained random forest
    % RFCLASSIFIER loads the trained random forest from
    % 'DigitImagesRF.mat', and predicts labels for new observations based
    % on the trained model. The random forest in 'DigitImagesRF.mat'
    % was cross-validated using the training data in the sample data
    % 'DigitImages.mat'.

    properties (Access = private)
        CompactRF % The compacted, trained random forest
    end

    methods (Access = protected)
        function setupImpl(obj)
            % Load random forest from file
            obj.CompactRF = loadLearnerForCoder('DigitImagesRF');
        end

        function y = stepImpl(obj, u)
            y = predict(obj.CompactRF, u);
        end

        function flag = isInputSizeValidImpl(obj, index) % ok<INUSD>
            % Return false if input size is not allowed to change while
            % system is running
            flag = false;
        end

        function dataout = getOutputDataTypeImpl(~)
            dataout = 'double';
        end

        function sizeout = getOutputSizeImpl(~)
            sizeout = [1 1];
        end
    end
end
Majority of machine Learning models are supported for Deployment

**Supported Models**
- Linear Classification
- SVM
- Decision trees and Random Forests
- Linear Discriminant Analysis
- k-Nearest Neighbor models
- Ensemble models
- Naïve Bayes models
- Gaussian Process
- Linear/Generalized Linear Regression models
- Regression

**Simulink**
- MATLAB Function Block
- MATLAB System Block
- Stateflow

**Deploy machine learning models in MATLAB & Simulink**
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Deploy reduced precision machine learning models

In-place modification of deployed models

fixdt(1,8,3)

1 0 1 1 0 0 1 0

Real world value: -9.75
Deploy reduced precision machine learning models

Minimize energy consumption on EV’s
Reduce cost

Real world value: -9.75
Reduced precision workflows allow conversion to fixed-point and deployment of models with small memory footprint.

Train in MATLAB

Supervised Learning

CLASSIFICATION

REGRESSION

Model

Fixed-Point Representation of Model

New Data

Fixed-Point Implementation of Predict

Convert in Fixed-Point Designer

Cost-effective model

Predict on low power embedded device

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Predict on low power embedded device
Fixed-point conversion is a trade-off between resource usage optimization and accuracy.
Most Popular machine learning models are supported for fixed-point workflows

**Reduced Precision: Supported Models**

- SVM
  - Multi-class not supported
- Decision Trees
- Ensembles of Decision Trees

*Deploy reduced precision machine learning models*
Deploy machine learning models in MATLAB & Simulink

Deploy reduced precision machine learning models

In-place modification of deployed models

```matlab
fixdt(1,8,3)
```

1 0 1 1 0 0 1 0

Real world value: -9.75
In-place modification of deployed models

Update running model

No code regeneration, no redeployment

SIL/HIL Verification of models

OTA Update of models on remote vehicles
In-place modification of deployed models allows model updates without code regeneration.
In-place modification workflow is agnostic to communication method, works in Simulink

Modified version of openExample('stats/HARDeploymentExample')
Most Popular machine learning models are supported for in-place modification workflows

In-place modification: Supported Models

- SVM
- Linear Models
- Decision Trees
Machine Learning algorithms are supported for a variety of embedded systems workflows

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In-place modification of deployed models

$$\text{fixdt}(1,8,3)$$

1 0 1 1 0 0 1 0

Real world value: -9.75
Are you already working on a project that involves deploying a machine learning model to an edge device?

A  YES

B  NO

If you have questions, please reach out:

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