How Machine Learning Techniques Could Help in Control Systems

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Workshop

Alessia Bozzini

UNIVERSITÀ di VERONA
Dipartimento di INFORMATICA

Agenda

- Machine learning Supervised
- Control system
- Methodology
- MATLAB and Simulink
- Example

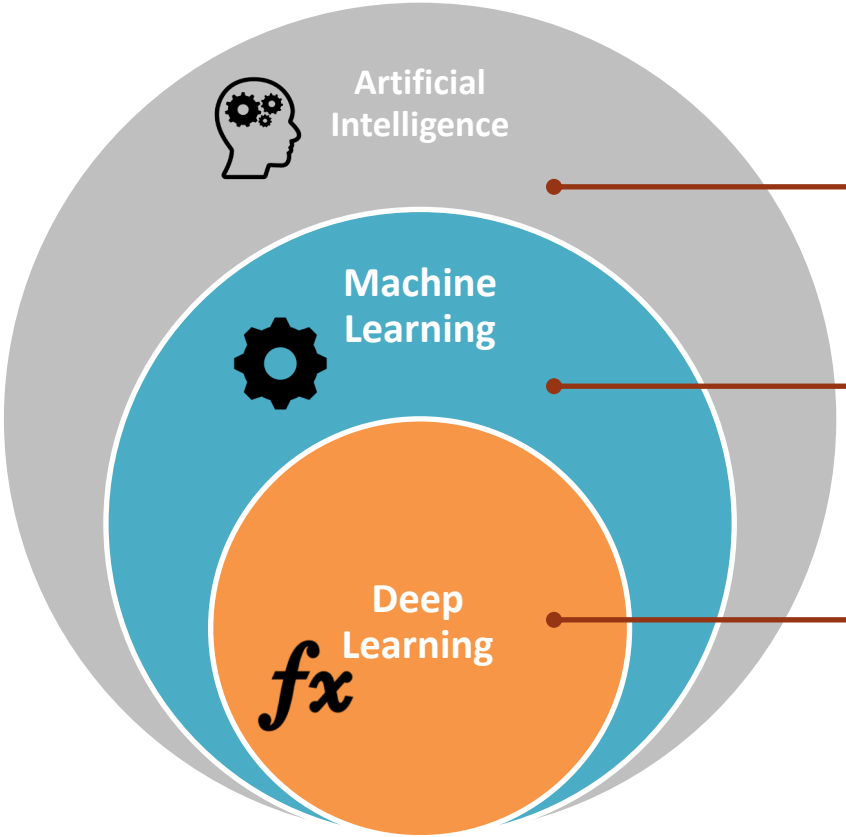
Machine learning Supervised

Control system

Methodology

BACKGROUND

Machine Learning



Artificial Intelligence

Any technique which enables computers to mimic human behavior

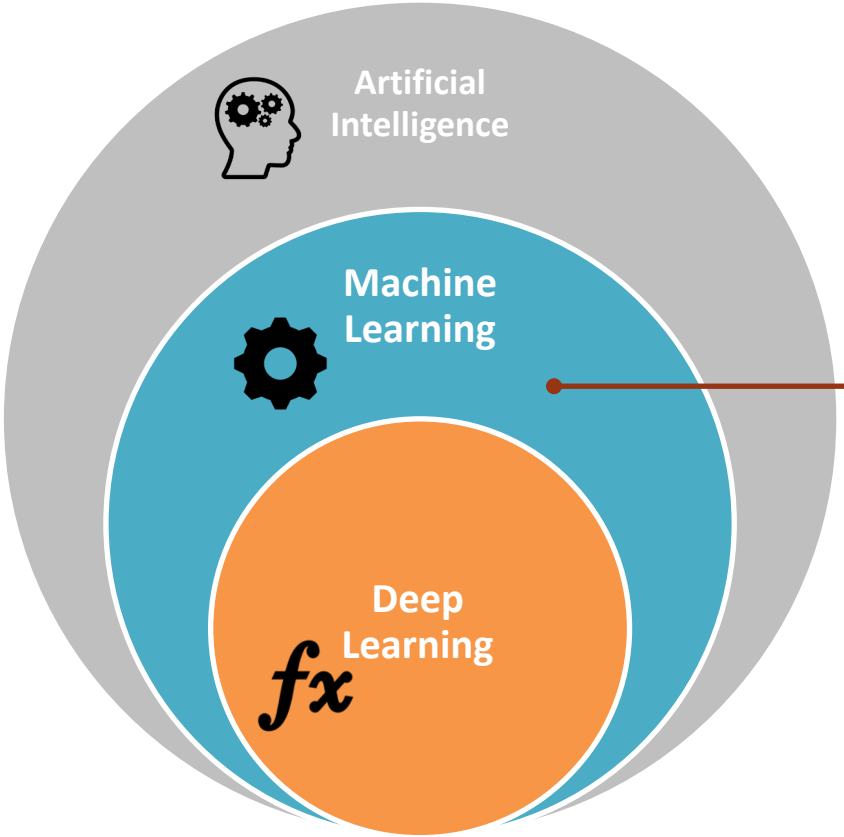
Machine Learning

Subset of AI techniques which use statistical methods to enable machines to improve with experience

Deep Learning

Subset of ML which make the computation of multi-layer neural networks feasible

Machine Learning

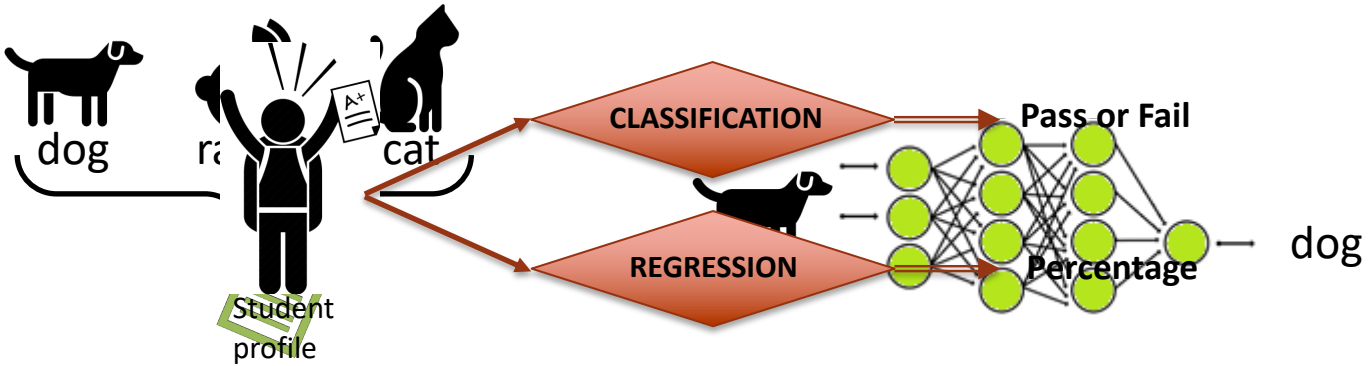


Machine Learning

- **Supervised**
  - Example + solution
- **Unsupervised**
  - Example without solution
- **Reinforcement learning**
  - Example + goal

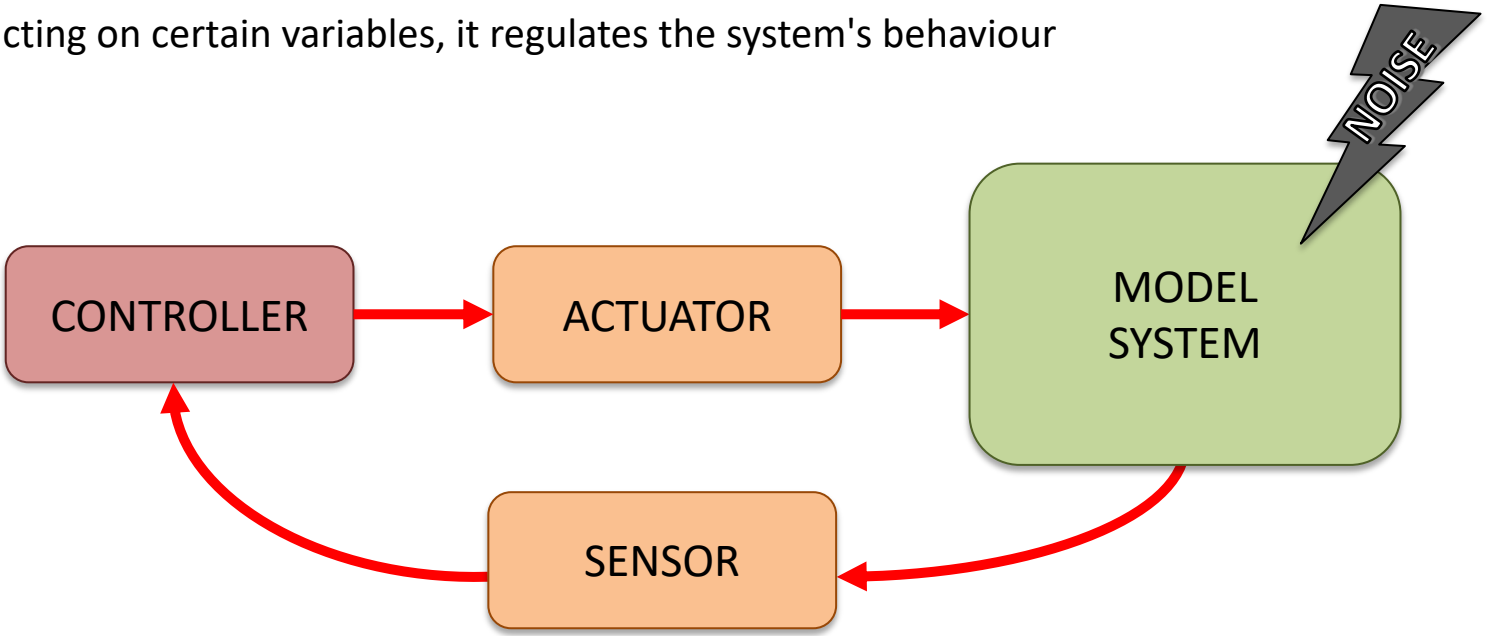
Machine Learning: **Supervised**

- Having **inputs** and related **outputs**, the **rule** that associates the inputs to the outputs is extracted
  - Classification → *discrete* response (i.e. ON/OFF, 0/1/2, dog/cat/rabbit …)
  - Regression → *continuous* response



Control system

- A control system manages, commands, directs, or regulates the behavior of other devices or systems using control loops
  - acting on certain variables, it regulates the system's behaviour



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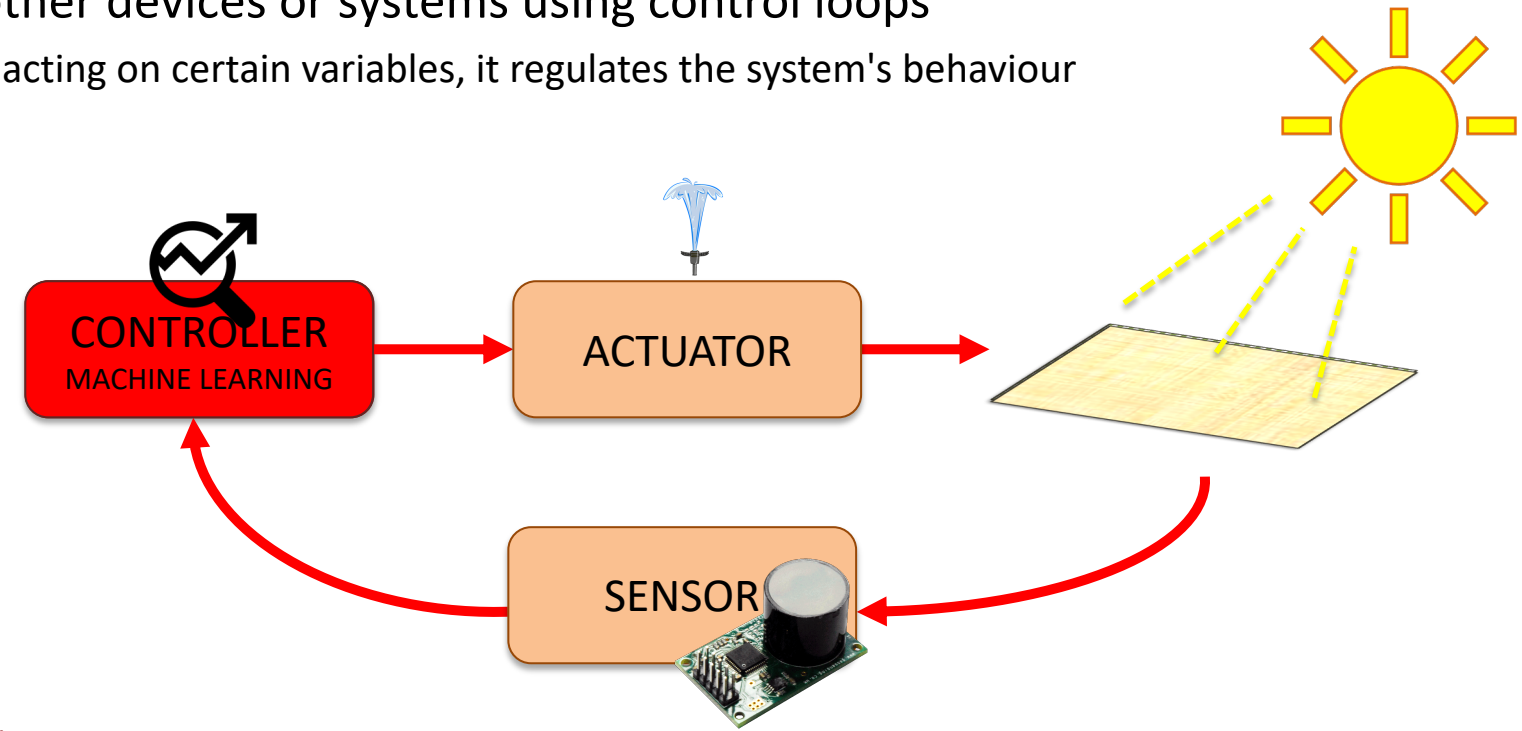
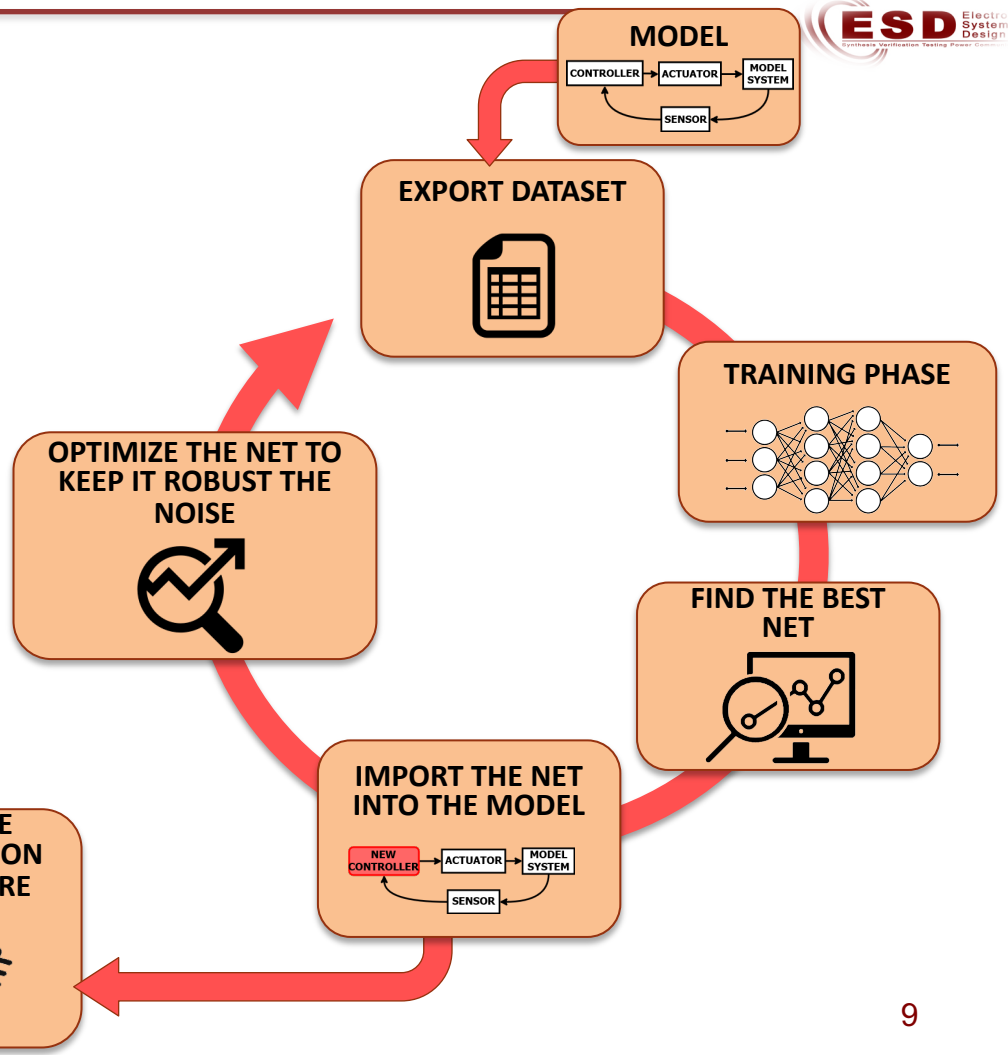


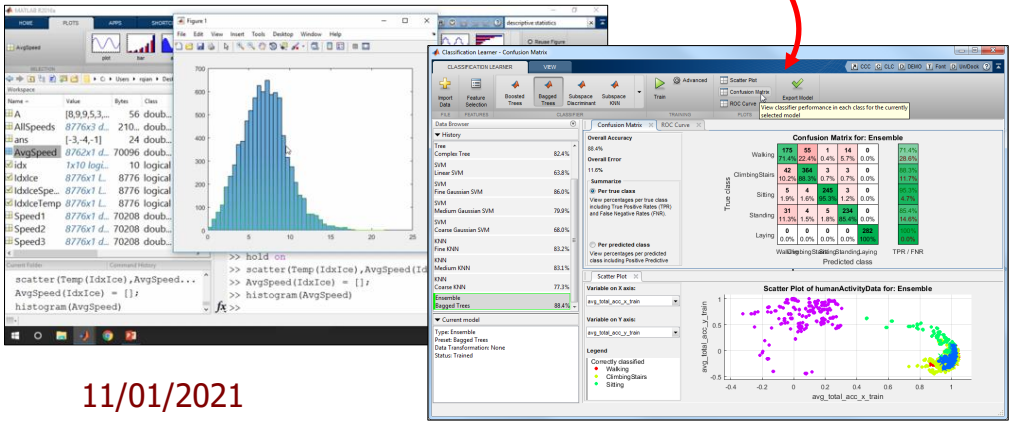
Methodology

- Main steps are:
  - Export the dataset
  - Build of the trained NET
  - Implement in system
  - Optimize the NET
  - Generate the code

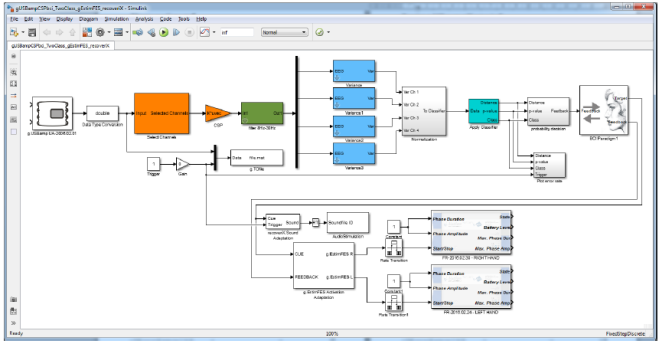


Development environment

- The **MATLAB** environment
  - Is an environment for numerical calculation and statistical analysis
  - Allows the use of machine learning techniques
    - Classification Learner App
    - Regression Learner App



- The **Simulink** environment
  - Allows construction of the simulation environment for the hardware and software design of a system
  - Is closely integrated with MATLAB



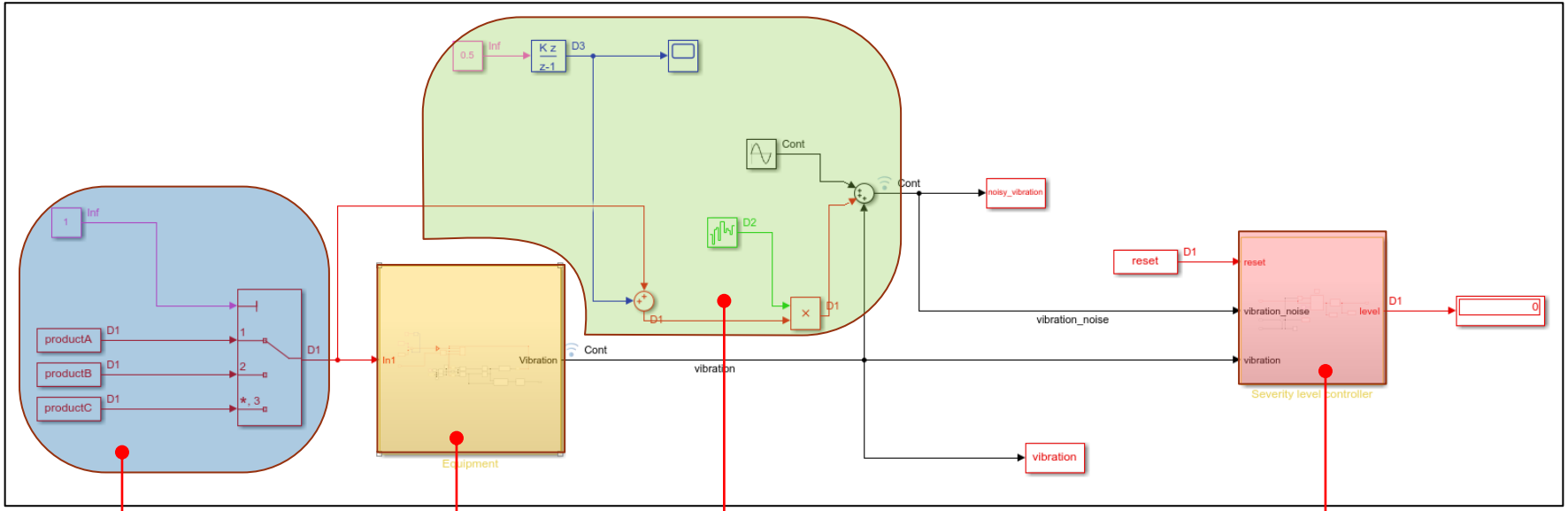
CASE STUDY: FAILURE OF A DRIVE SHAFT OF A MACHINE

Model scheme

- The machine produces a product in 50 seconds
- There are 10 seconds between one production and the next
- The vibration of the machine is monitored

MATLAB tools dependency

- **Simscape Driveline** version 2.15
- **Simscape** version 4.5



Type of product | Machine | fault injection | Severity level controller

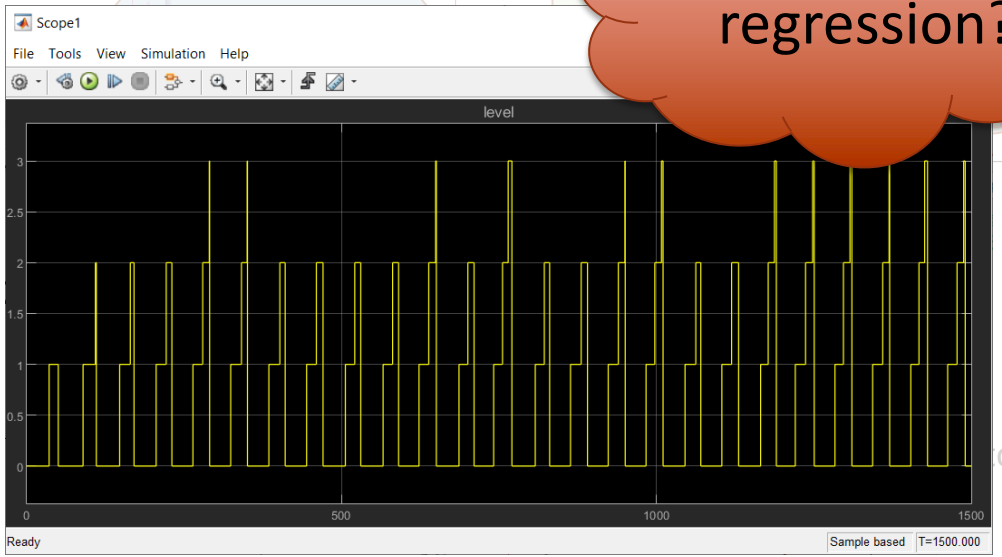
Goal

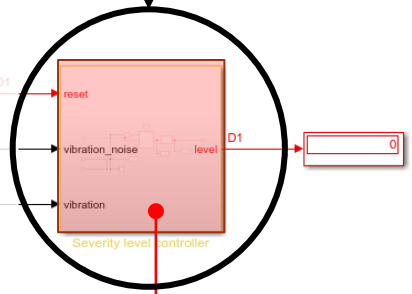
Replicate the behavior

Classification or regression?

rity level:

- 0 = Minimal
- 1 = Small
- 2 = Medium
- 3 = Large



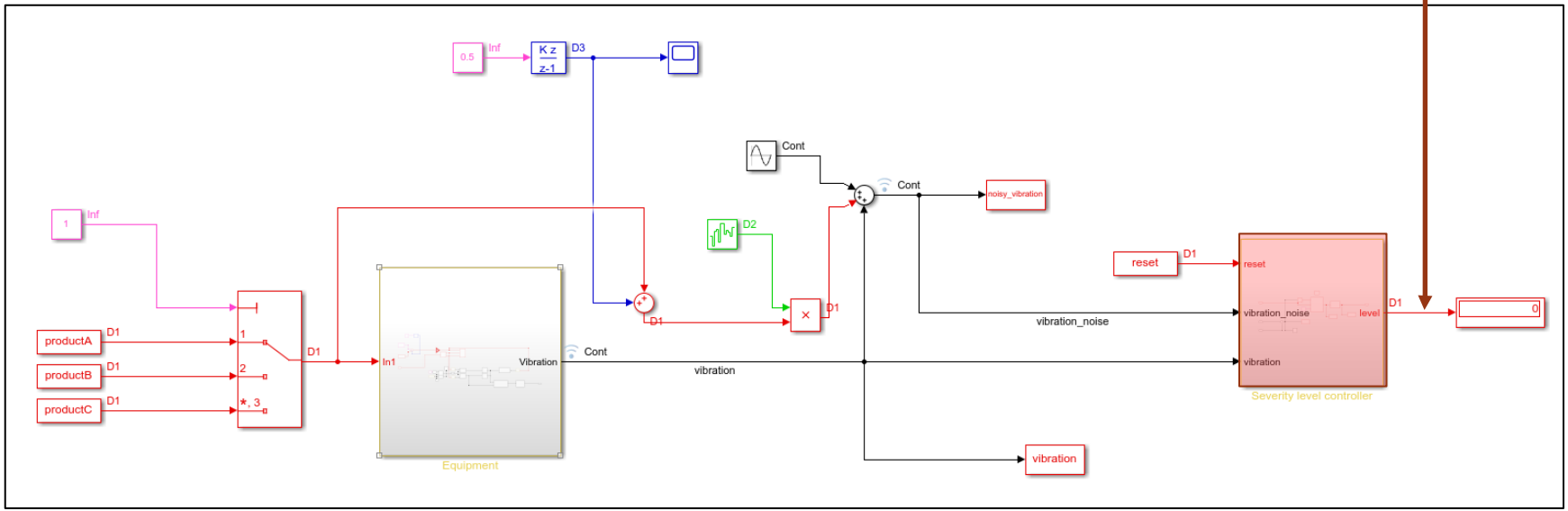


Severity level controller

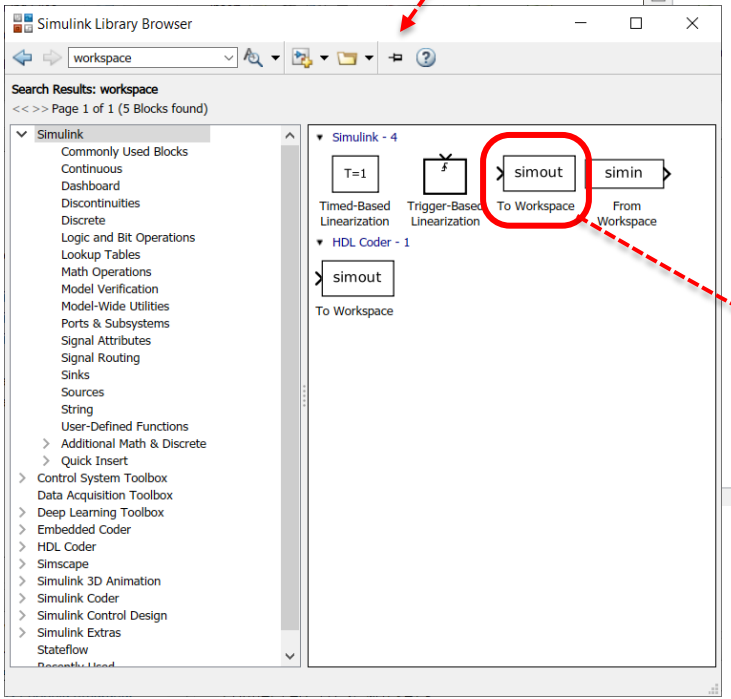
Dataset generation

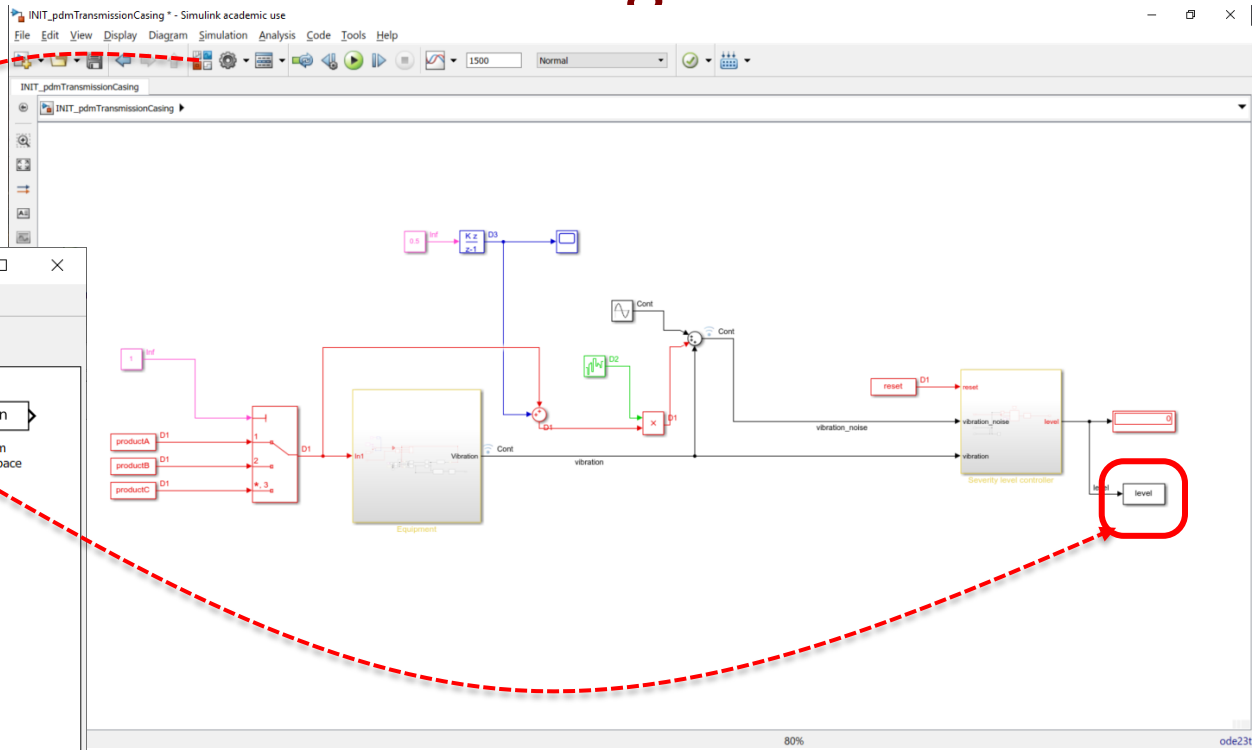
- Training dataset

  [inputs | level]



How to observe the signal





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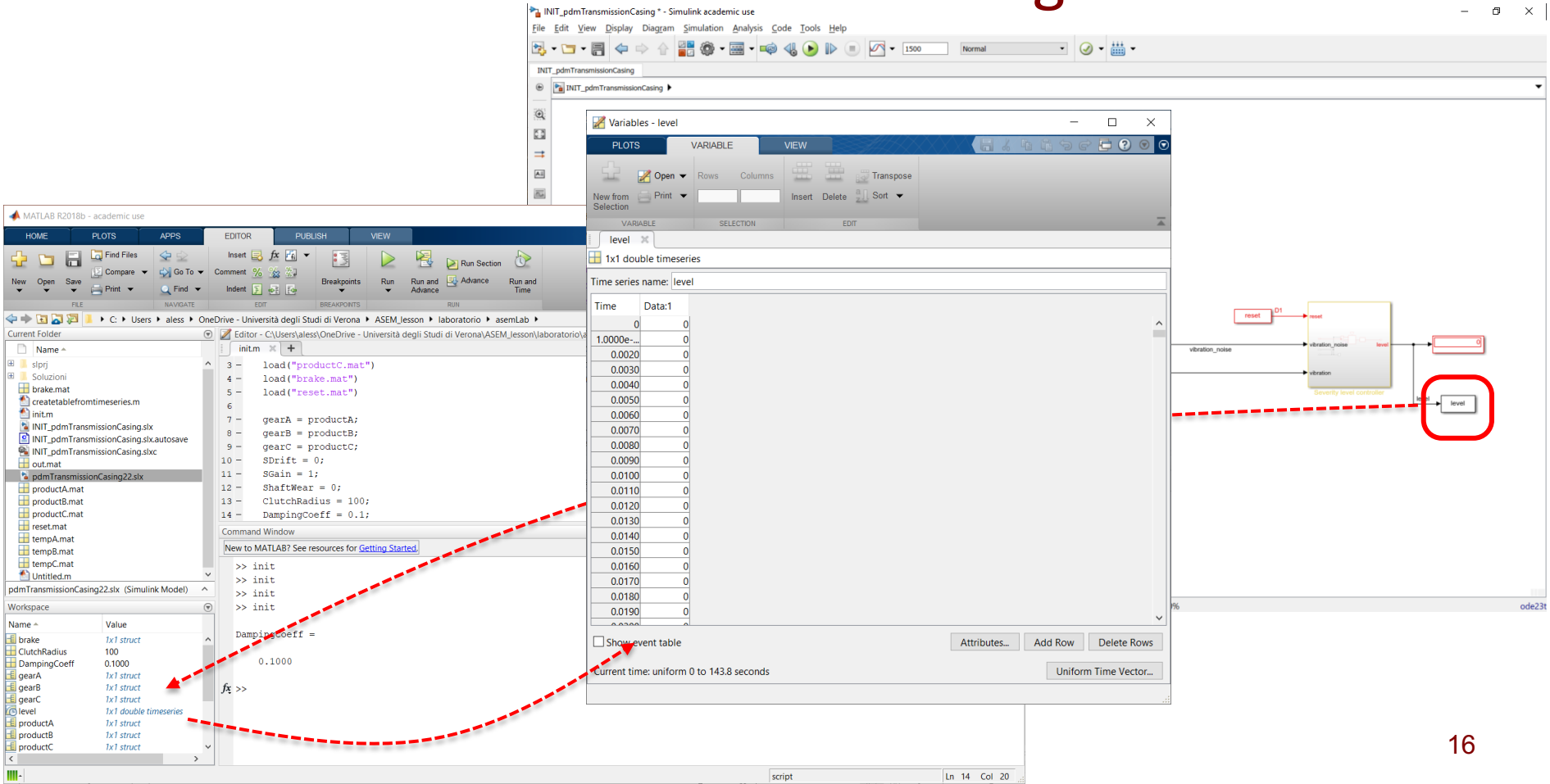


Dataset generation

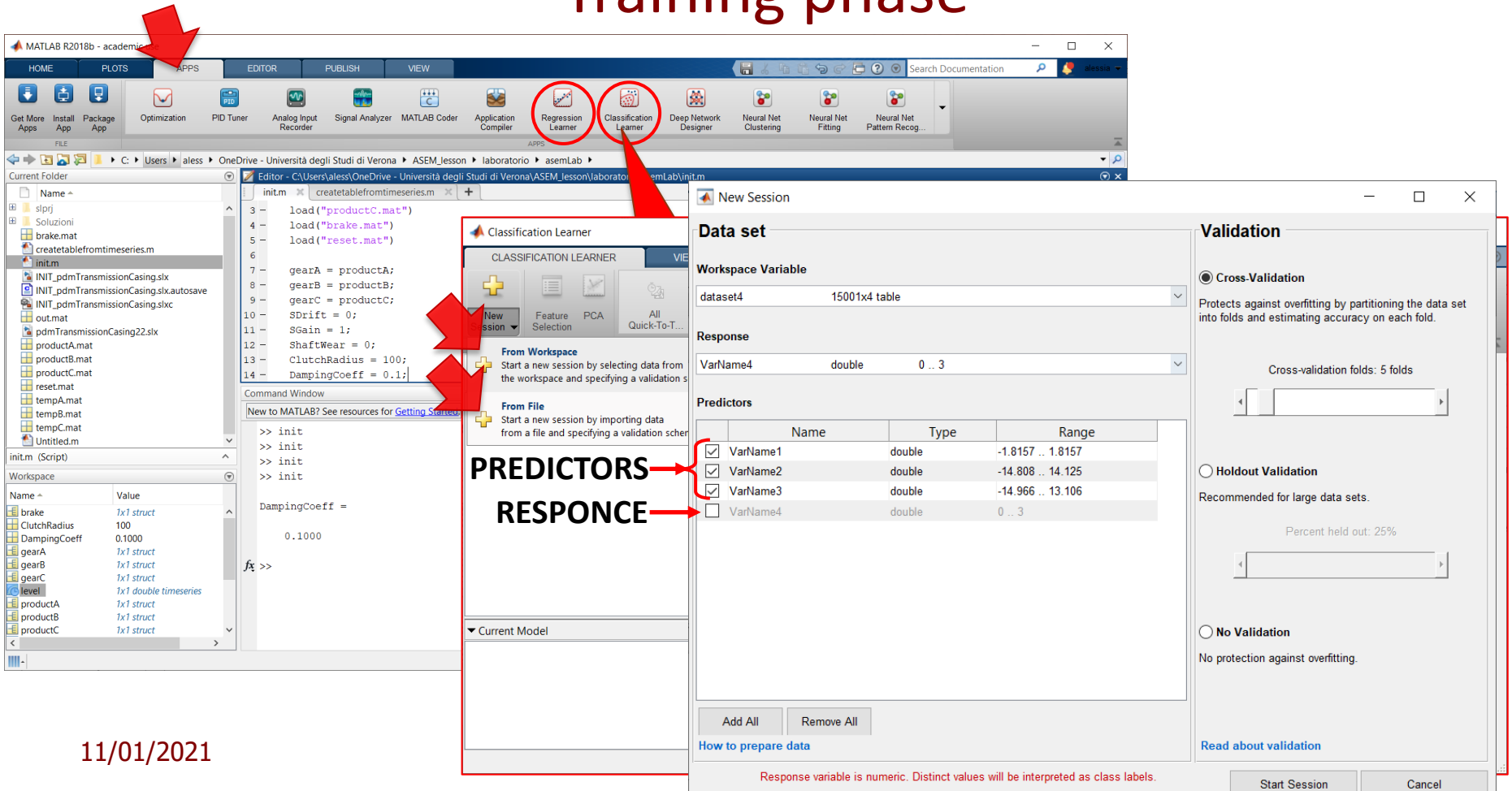
- Dataset
  1. Build a matrix

```
A = [signal.Data  signal2.Data   … ]);
```

  2. Save dataset in a CSV file

```
csvwrite("dataset.csv",[ double(signal.Data), double(signal2.Data) … ]);
```

Training phase



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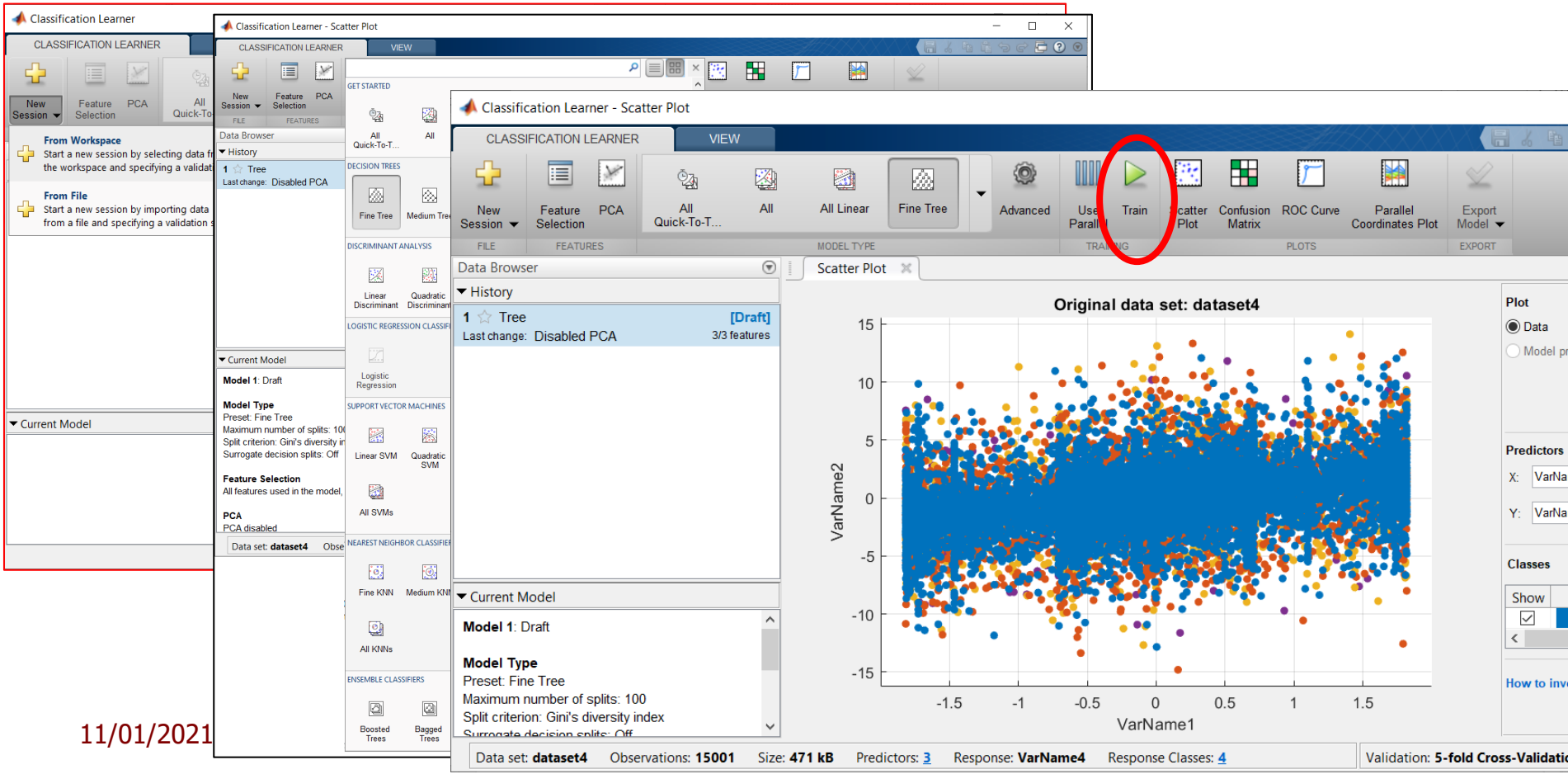
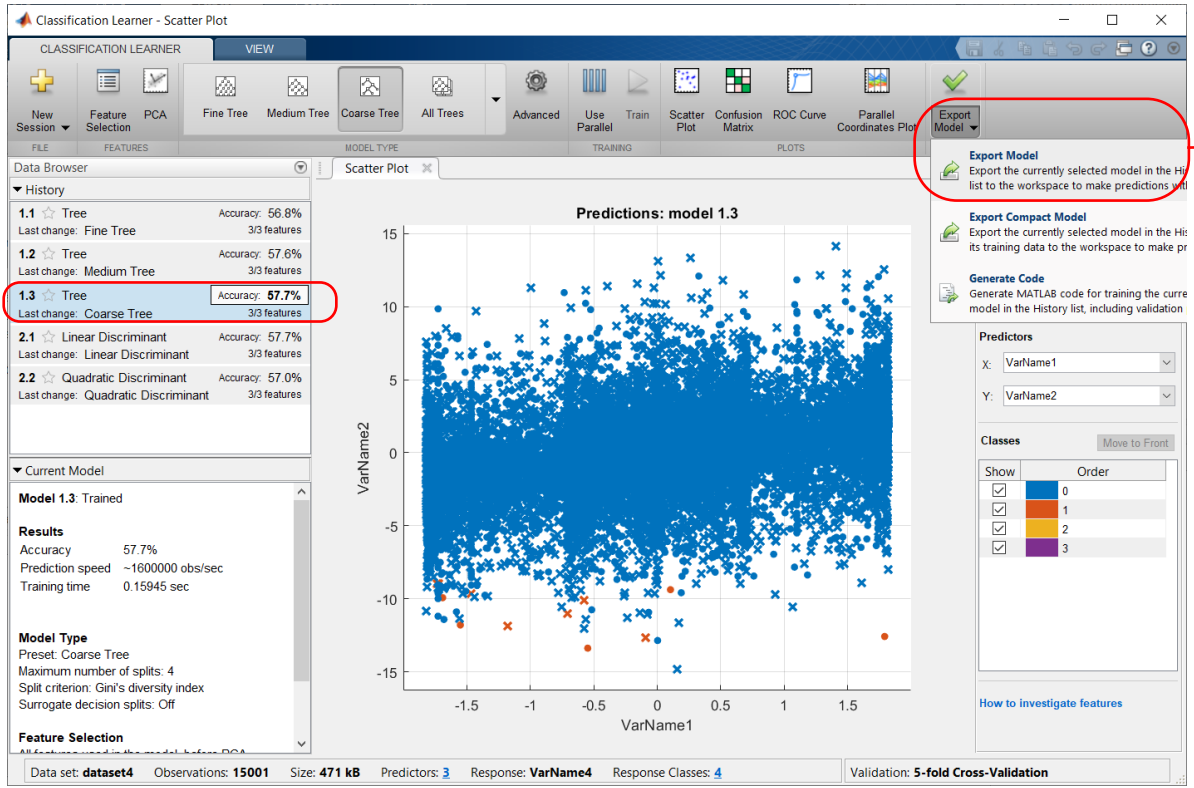
Training phase



Training phase and prediction phase



MATLAB

```
saveCompactModel(
      trainedModel.ClassificationTree,
      "myclass.mat")
```

Simulink

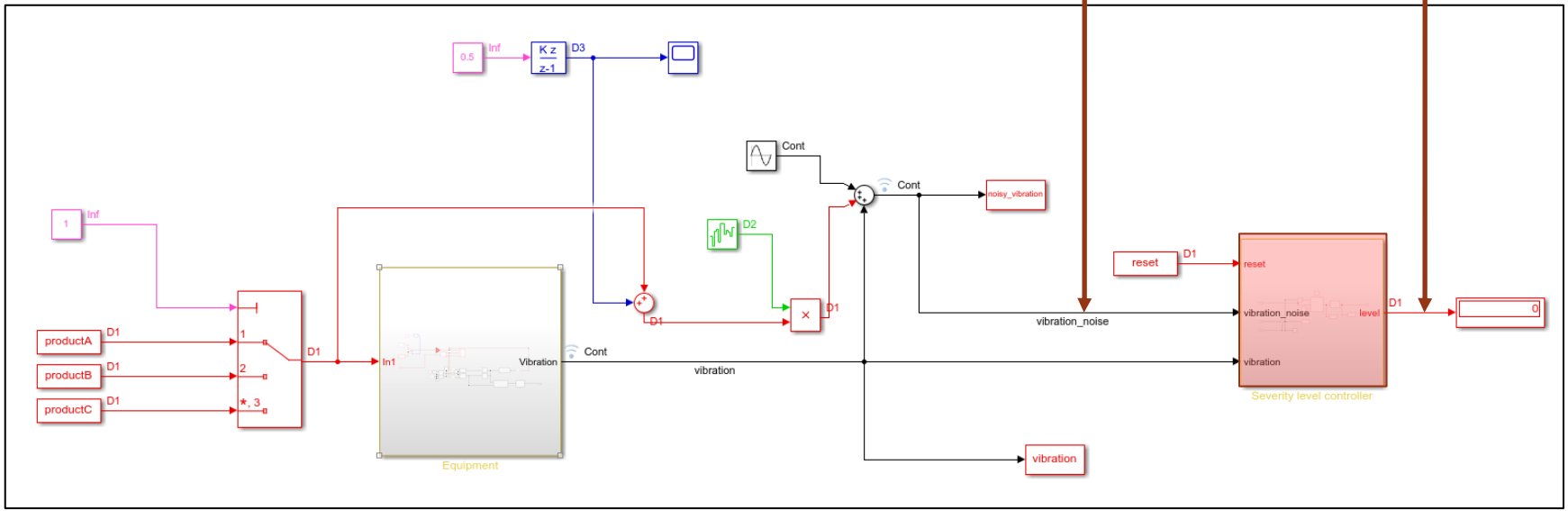

```
function y = fcn(signal1, signal2, signal3)

mdl = loadCompactModel("myclass.mat");
u = [signal1 signal2 signal3];
y = predict(mdl,u);
```

Solution 1

- Build the following dataset

[vibration_noise level]



MATLAB exercise

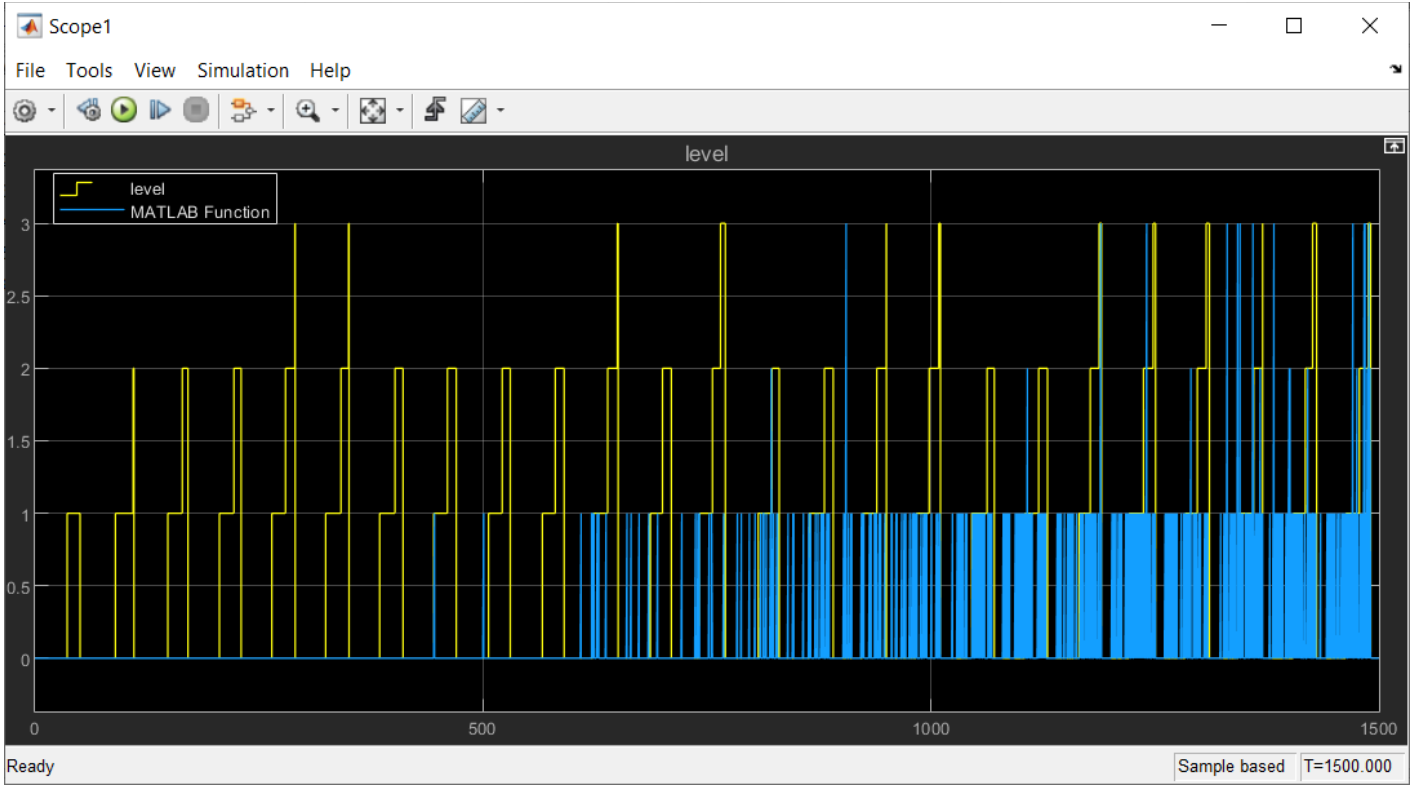
- Run MAT file

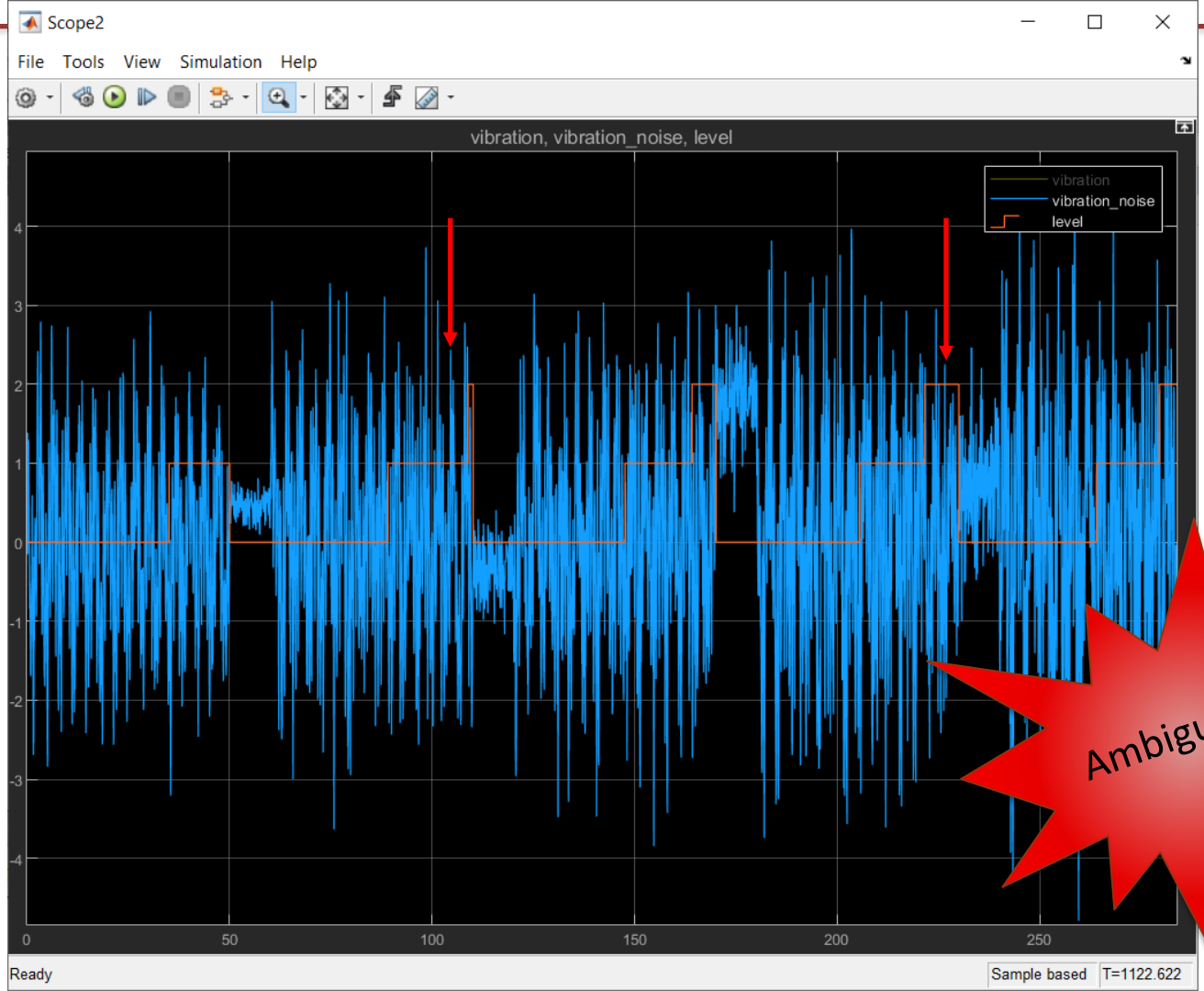
  init.mat

- Run model

  INIT_pdmTransmissionCasing.slx

Dataset: [vibration_noise; level]

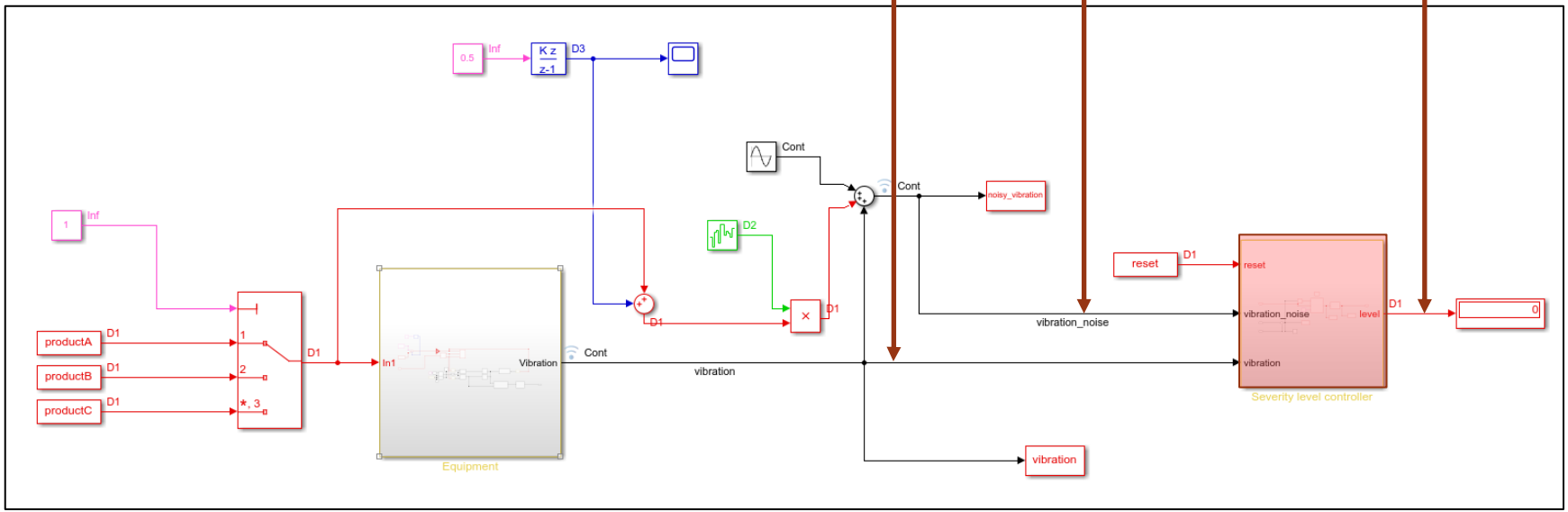



Scope2
File Tools View Simulation Help
vibration, vibration_noise, level
vibration
vibration_noise
level
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
Ready
Sample based
T=1122.622
Ambiguities

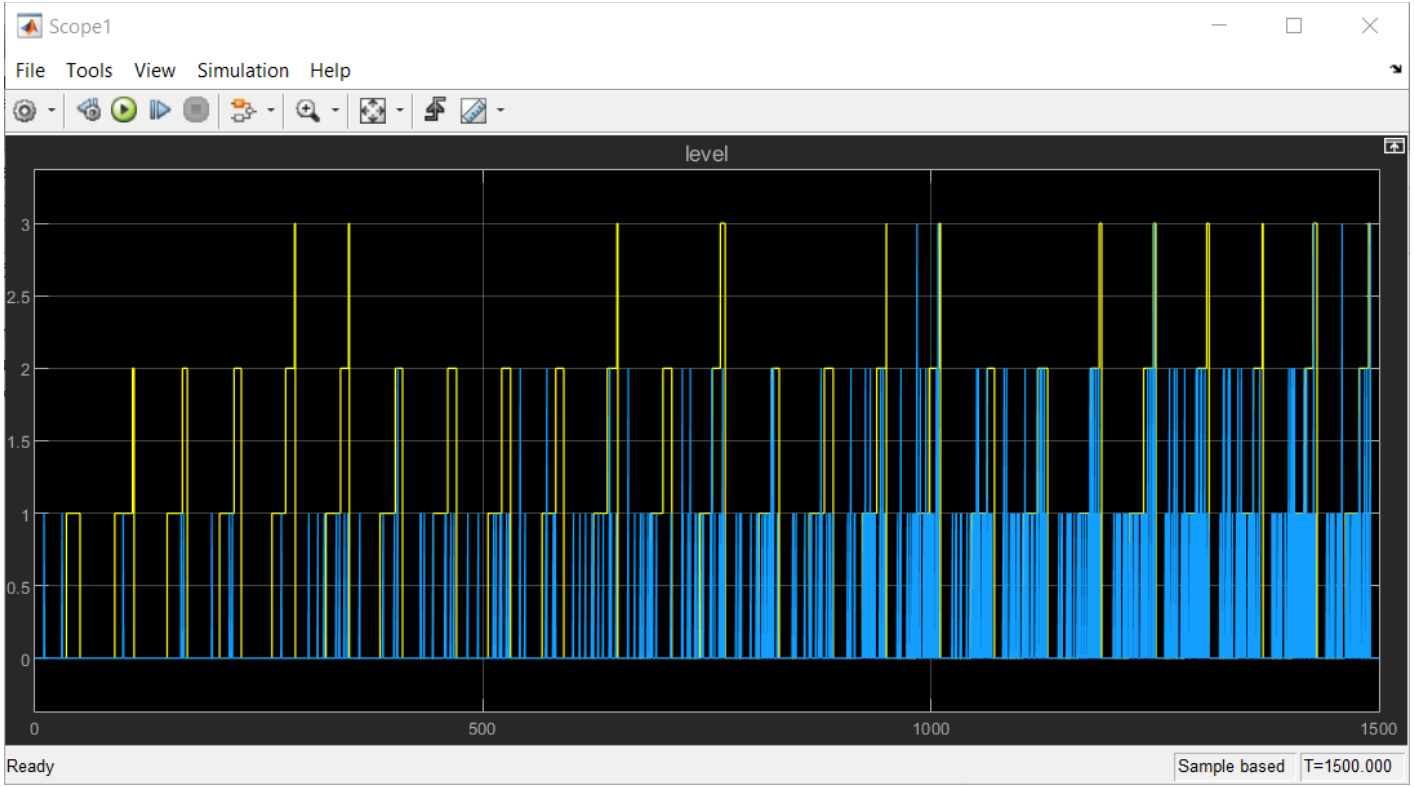
Solution 2

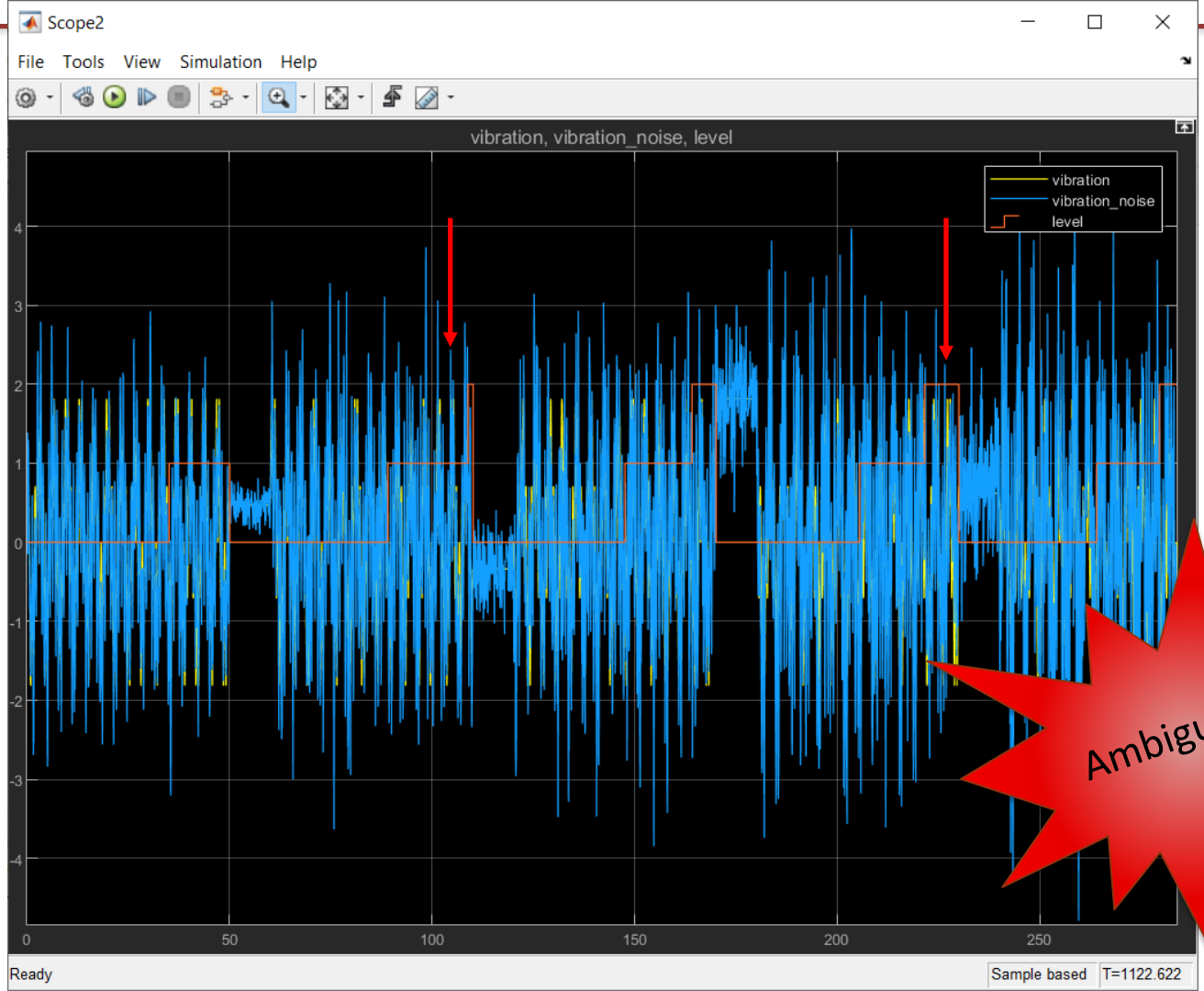
- Build the following dataset

[vibration vibration_noise level]



Dataset: [vibration; vibration_noise; level]

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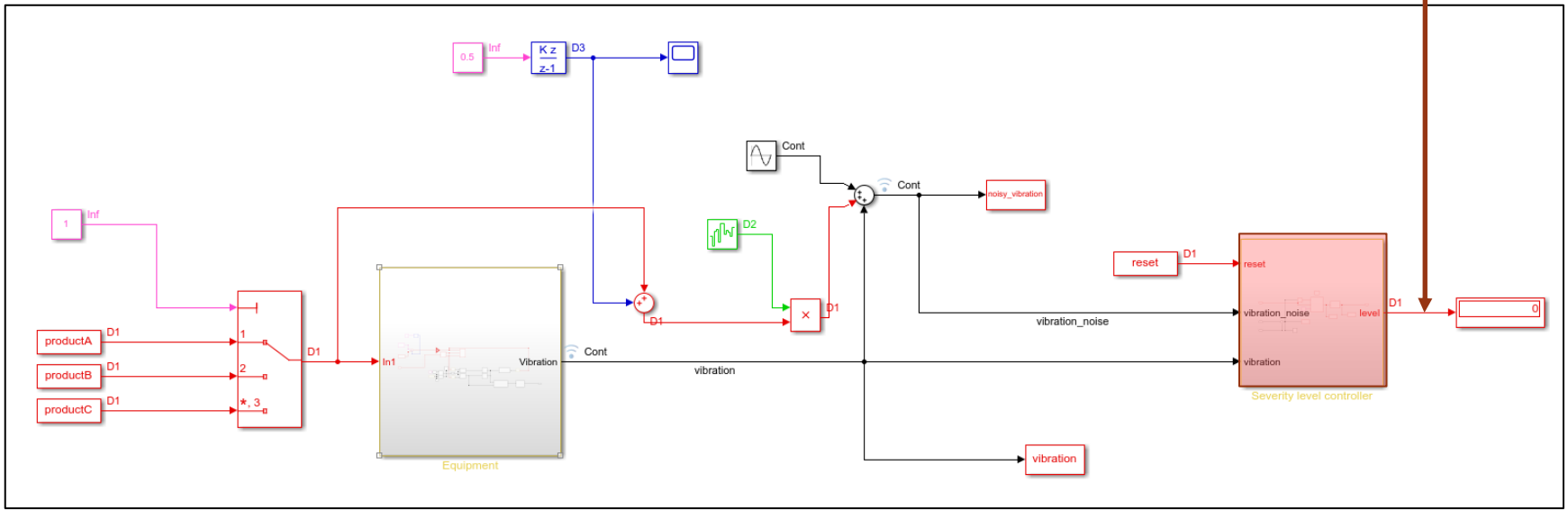
Ambiguities

Solution 3

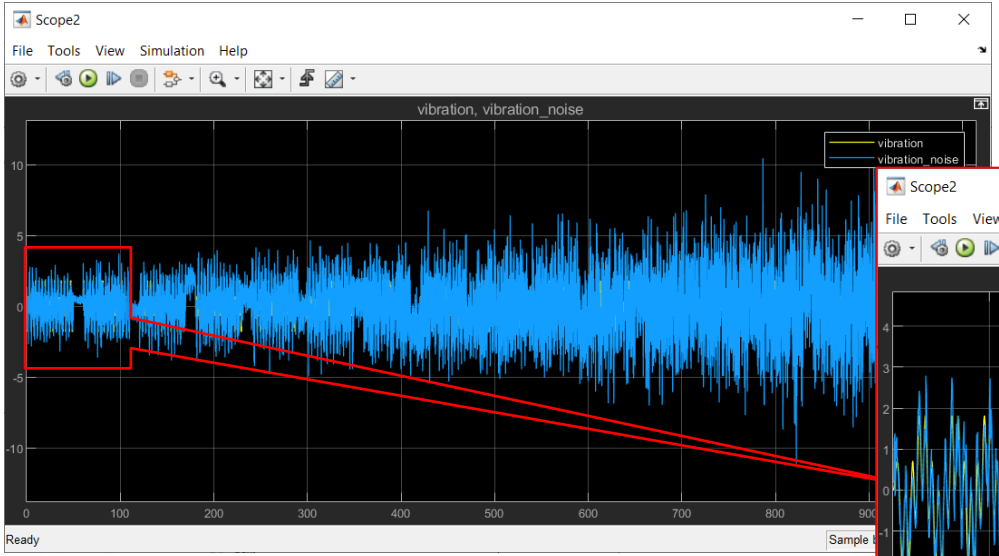
- Build the following dataset

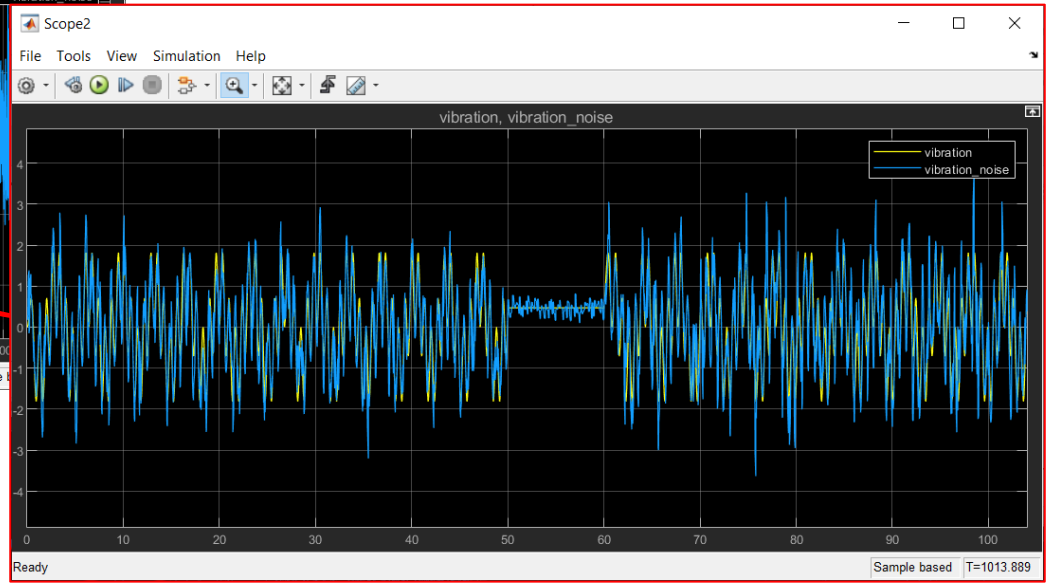
  [counter level]



Solution 3

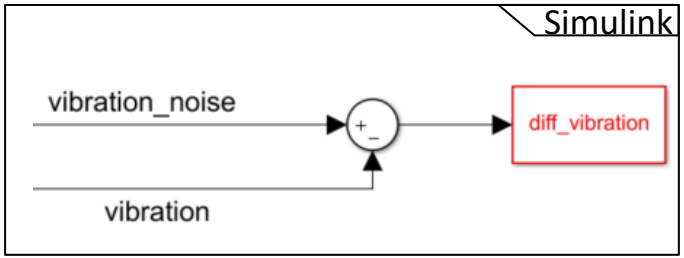
- Counter: how many times the vibration with the fault deviates from the desired one, within a certain tolerance





Dataset generation

- Build dataset: [counter level]



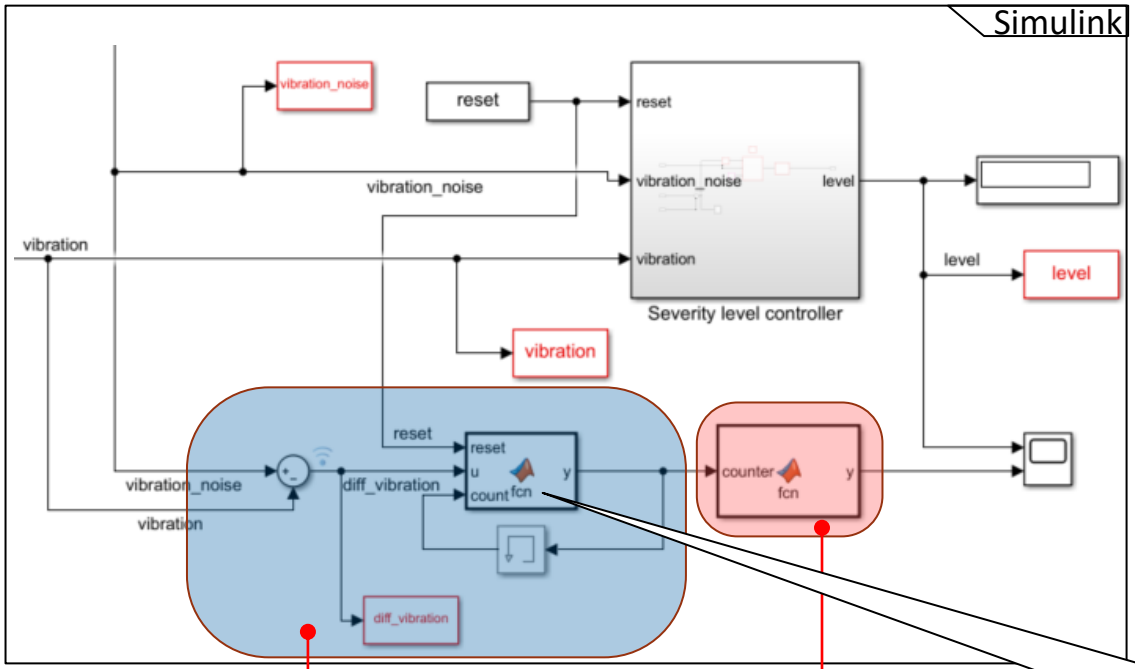
MATLAB

```
[n,m] = size(diff_vibration.Data)
tolerance = 0.1;
counter = zeros(n,1);
j = 1;
for i = 2:n
    j = mod(i,60001)+1;
    if (reset.signals.values(j)) == 1
        counter(i) = 0;
    elseif diff_vibration.Data(i) > tolerance
        counter(i) = counter(i-1) +1;
    else
        counter(i) = counter(i-1);
    end
end

A = [counter level.Data];
```

Find the best tolerance

Prediction phase



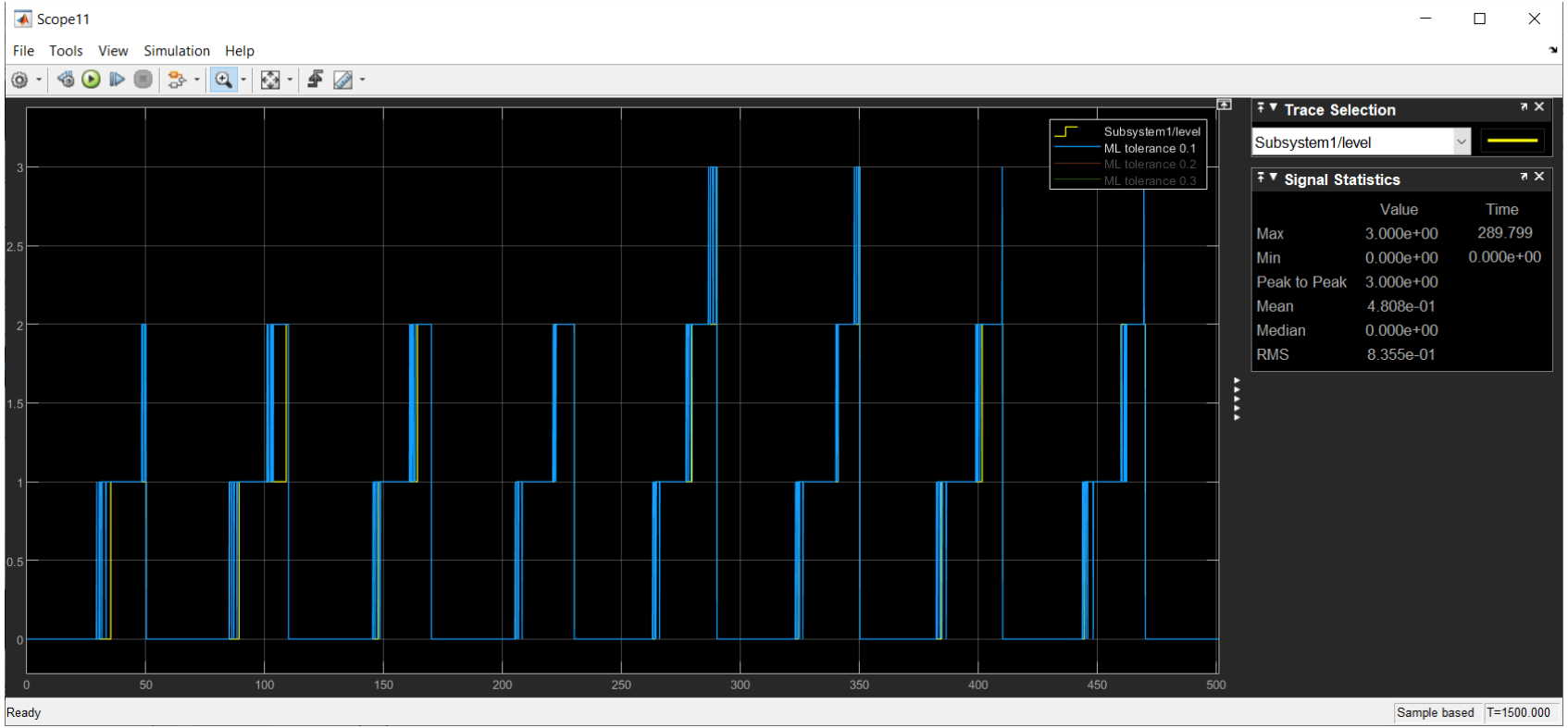
To calculate counter at runtime

contains the machine learning algorithm

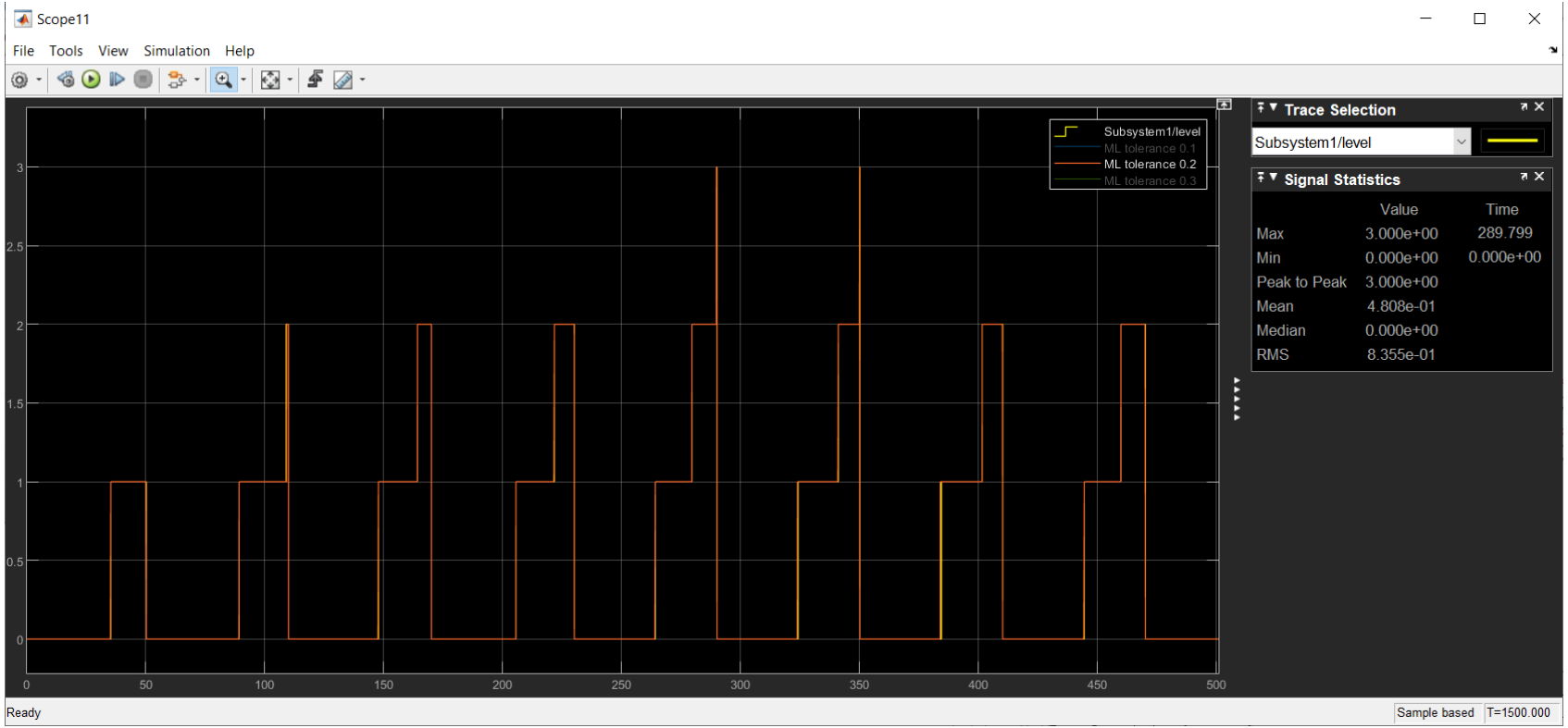
```
function y = fcn(reset, u, count)
    tolerance = 0.1;
    if reset==1
        count=0;
    end

    if u > tolerance
        count = count+1;
    else
        count=count+0;
    end
    y = count;
```

Dataset: [counter; level] with tolerance = 0.1



Dataset: [counter; level] with tolerance = 0.2



Dataset: [counter; level] with tolerance = 0.3