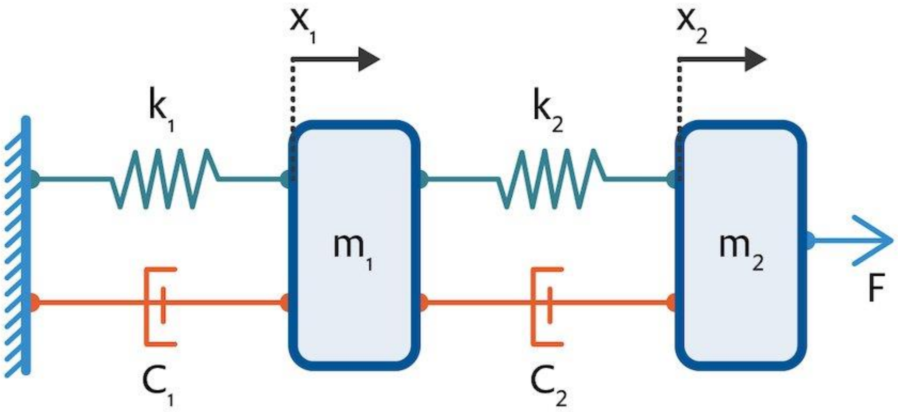
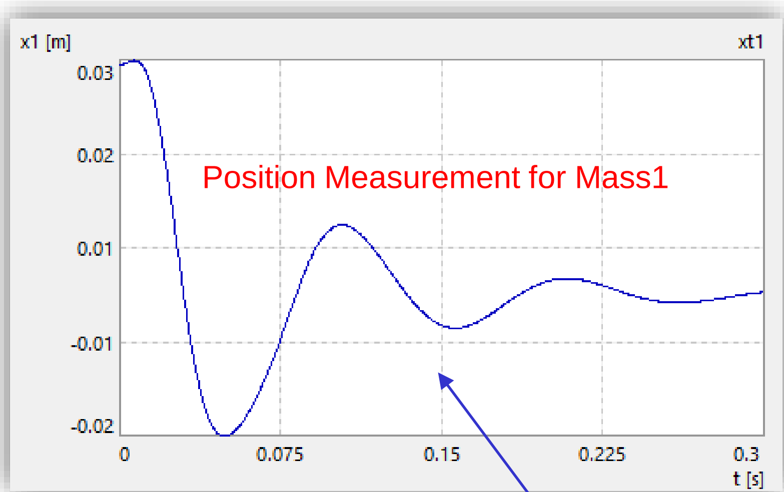
Novel Technology Case Study

Data-Driven Modeling and Simulation of a double Spring Mass Damper System



Imperfect Data and Physics of the System

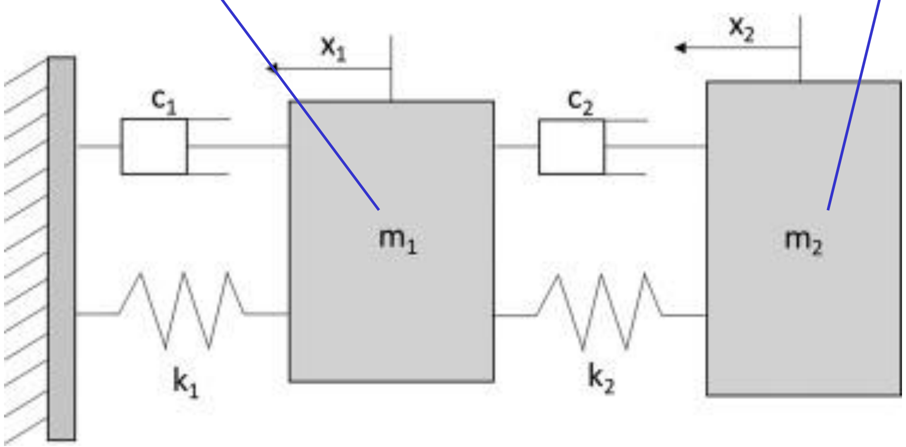


Partial Differential Equation for Mass 2

$$m_2\ddot{x}_2 + k_2(x_2 - x_1) + c_2(\dot{x}_2 - \dot{x}_1) = 0$$

Initial Conditions for Mass 2

$$x_2 = 0.055 \qquad \dot{x}_2 = 0$$



System-Modeling using Mix: Data + Physics

Hilbert Space	
Include X-Axis	☑
Include 1D-Variables	☐
X-Nonlinearity	None
Uniform Space	☐
t	
Covariance Function	Exponential
Number of Features	20
Gaussian Noise [%]	0.01
Approximation Error [%]	0
Regularization Weight	1
Include DOE	☑
Weight	1
Partial Differential Equatio	☐
Boundary Conditions	☐
Constraints	☐
Parameters	☐

Only Data for Mass 1

Hilbert Space	
Include X-Axis	☑
Include 1D-Variables	☐
X-Nonlinearity	None
Uniform Space	☐
t	
Covariance Function	Exponential
Number of Features	15
Gaussian Noise [%]	0.01
Approximation Error [%]	0
Regularization Weight	1
Include DOE	☐
Partial Differential Equation	☑
PDE	m2/k2*derivate(xt2,t,t)+c2/k2*derivate(xt2,t)-c2/k2*derivate(xt1,t)+xt2-xt1=0
Linear	☑
Sampling Level	5
Weight	1
Boundary Conditions	☑
Number of Boundaries	2
Boundary 1	
Initial Value	xt2=0.055
Number of fixed Values	1
Fixed Parameter	t
Sampling Level	5
Weight [0..1]	1
Boundary 2	
Initial Value	derivate(xt2,t)=0
Number of fixed Values	1
Fixed Parameter	t
Sampling Level	5
Weight [0..1]	1
Constraints	☐
Parameters	☐

Differential Equation for Mass 2

Initial Conditions for Mass 2

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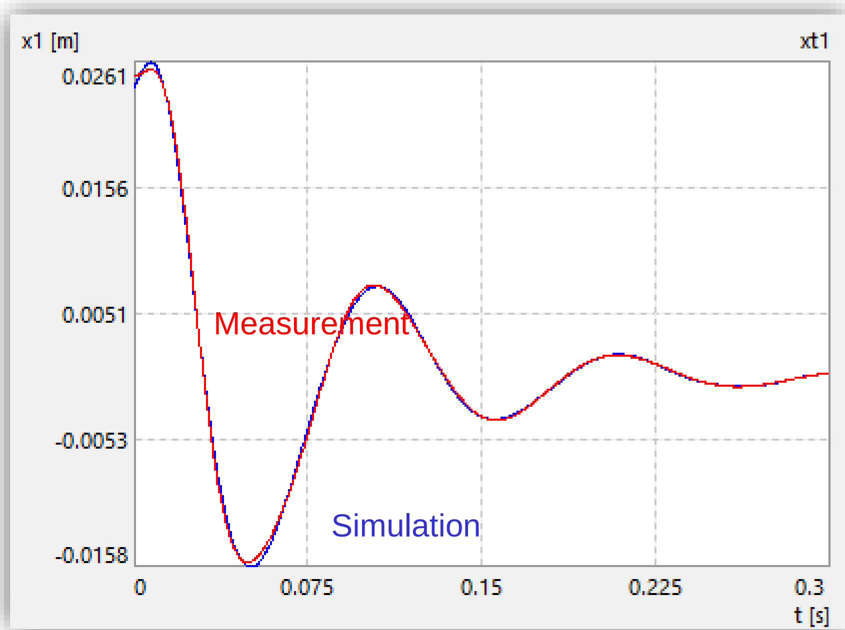
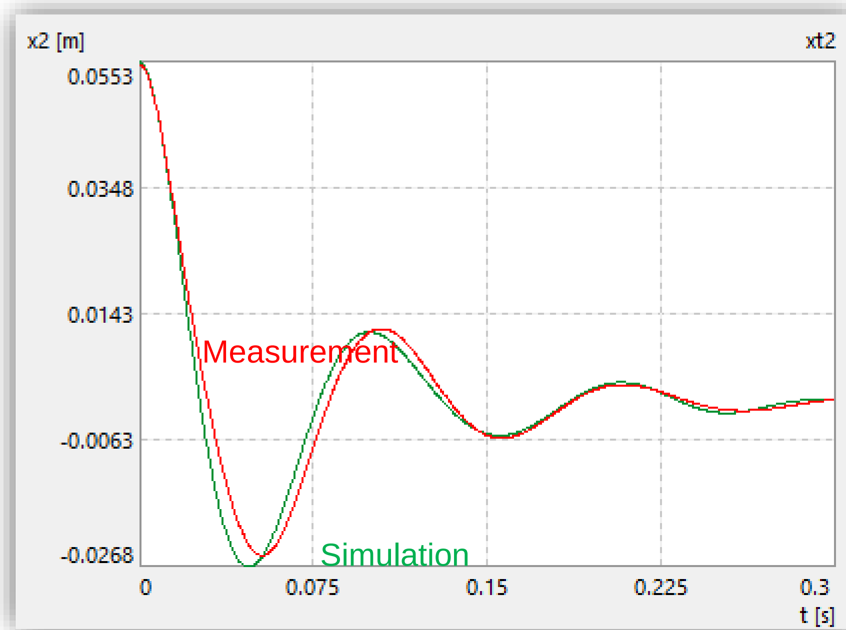
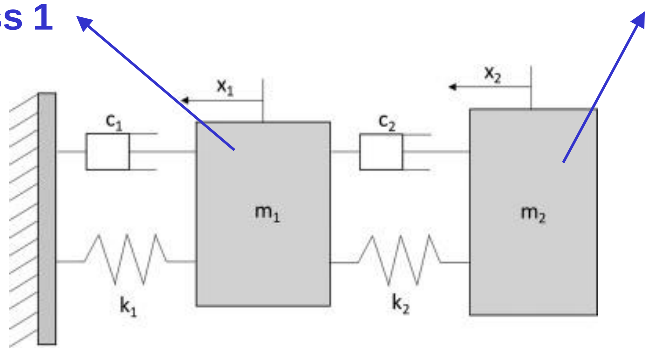
Real-Time Simulation and Measurement





Position for Mass 1

Position for Mass 2



Summary

- For the modeling system, there are sometime in the reality only imperfect data from measurement and imperfect physics in form of partial differential equation, initial condition or constraints. The goal is modeling and simulation of the total system behavoirs
- Physics-informed machine learning (PIML) is the best technology to solve this problem. Based on the Hilbert space, the meta-model can be modeled from both data and physics representing the system response.
- For the double spring mass damper system, there are only measurement data for the position of mass 1 and partial differential equation and initial conditions for mass 2. From these imperfect data and physics, the system response can be modeled and simulated in real-time. The simulation and measurement of the system response coincides totally.