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Parameter Estimation Methods for Fault Diagnosis using Modelica and FMI

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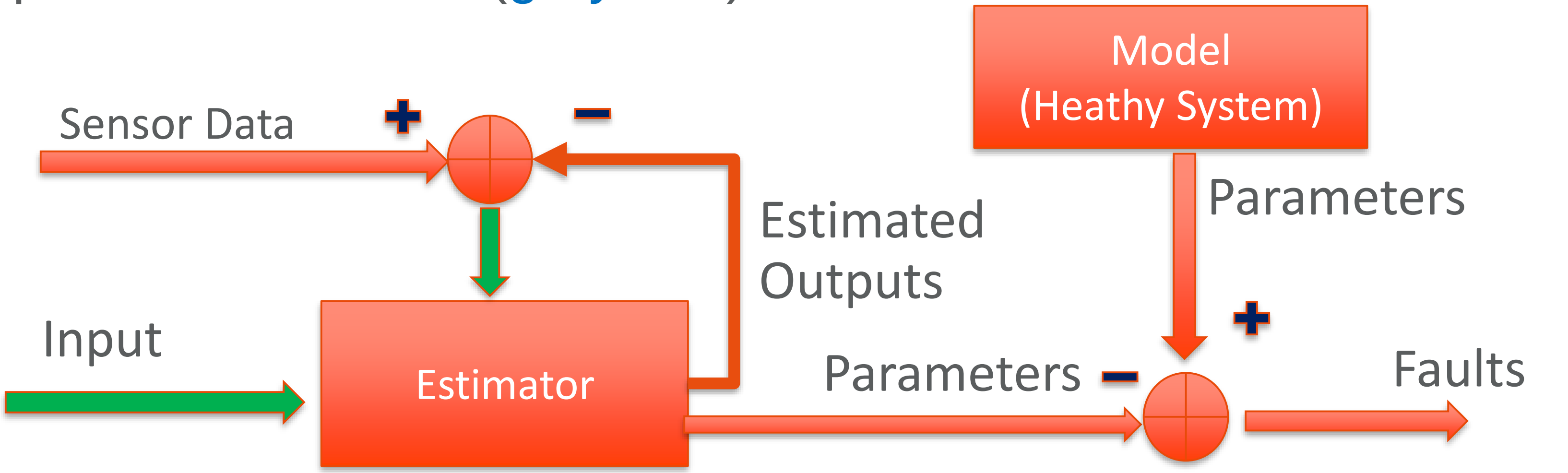
Outline

- Introduction
- Local Estimator
- Global Estimator
- Conclusions

Introduction

- Methods used for condition estimation of a physical asset into three broad categories:
    1. Methods use only data. (black-box)
    2. Methods utilize a physical model of the system. (white-box)
    3. Both previous methods. (grey-box)



- We present two different parameter estimation methods using Modelica and FMI namely ***local*** and ***global*** estimators.

Local Estimator

- The local estimator is implemented using Modelica and used to estimate parameters of one component inside the model.

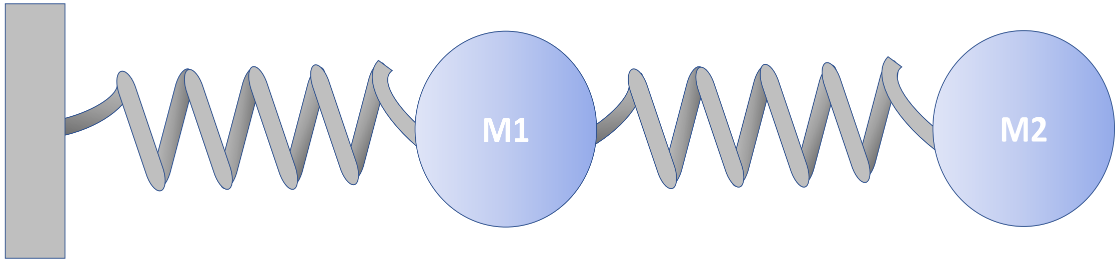
The actual model

The model with the Estimator

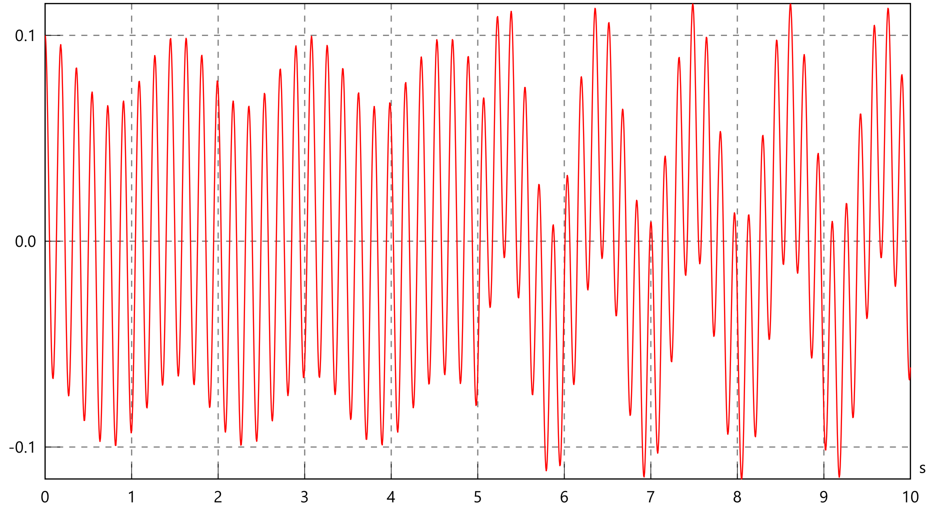
- The local estimator in this paper has been implemented in three different methods:
- 1) Direct Method 2) Recursive Least Squares 3) Particle Filter

Local Estimator

- The local estimators are used to estimate the change in the mass M1 which changed from 5kg to 2kg at t=5s. The displacement of the M2 is used as an input of the estimator to tune the value of the mass M1.



Two springs and masses system



Displacement of M2

Local Estimator

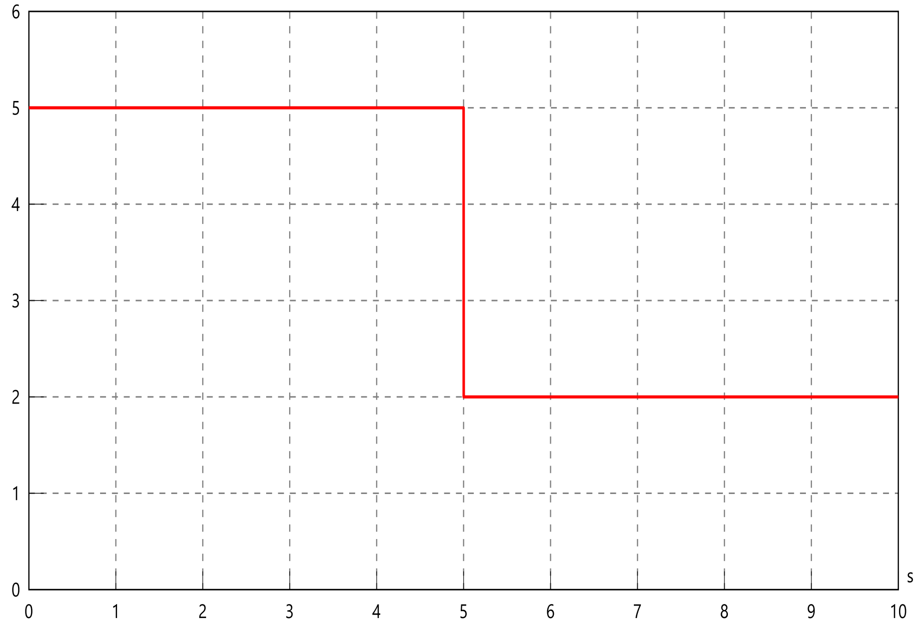
Direct Method

- Modify model to replace target parameters by unknowns.

```
parameter Real M1;      Real M1;
 Real x2;                input Real x2;
```

Target parameters	Replaced by	state variables
State variables	Replaced by	(sensor) inputs

- There needs to be a connected reference signal per parameter to be estimated.
- This estimator is:
  1. Very easy to implement.
  2. Very sensitive to noise in these signals.



Mass of M1 as a function of time

Local Estimator

Recursive Least Squares Estimation

- The recursive least squares method (RLS) is used on-line and off-line to estimate parameters of static and dynamic linear systems

$$y = X^T A = a_1 x_1 + a_2 x_2 \dots \dots + a_n x_n$$

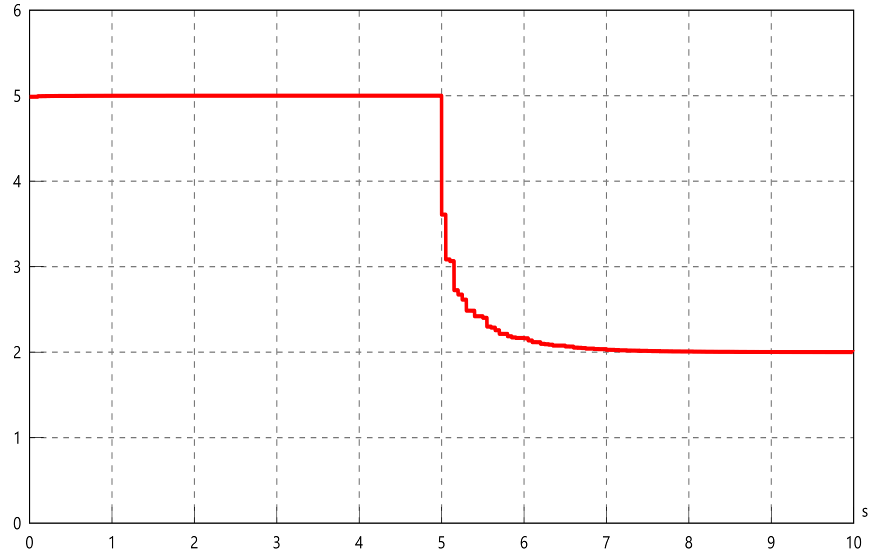
$$K_j = P_{j-1} X_j \left(1 + X_j^T P_{j-1} X_j\right)^{-1}$$

$$P_j = P_{j-1} - K_j X_j^T P_{j-1}$$

$$\hat{A}_j = \hat{A}_{j-1} - K_j \left(X_k \hat{A}_{j-1} - y_j\right)$$

Where j the current sample time,
K is the estimator gain,
P is the covariance matrix,
$\hat{A}$ is the parameters of the system

- This method is:
  1. Easy to implement.
  2. Robust against sensor noise.
  3. Only applicable to linear systems.

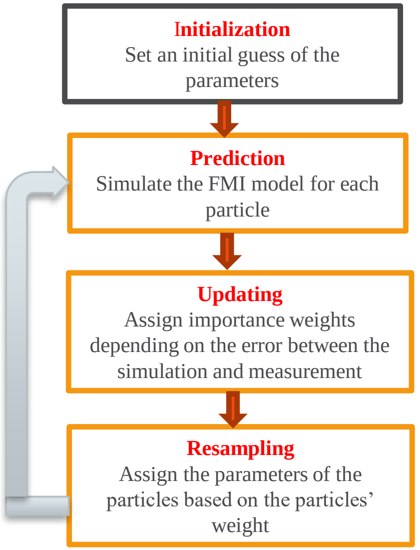


Mass of M1 as a function of time

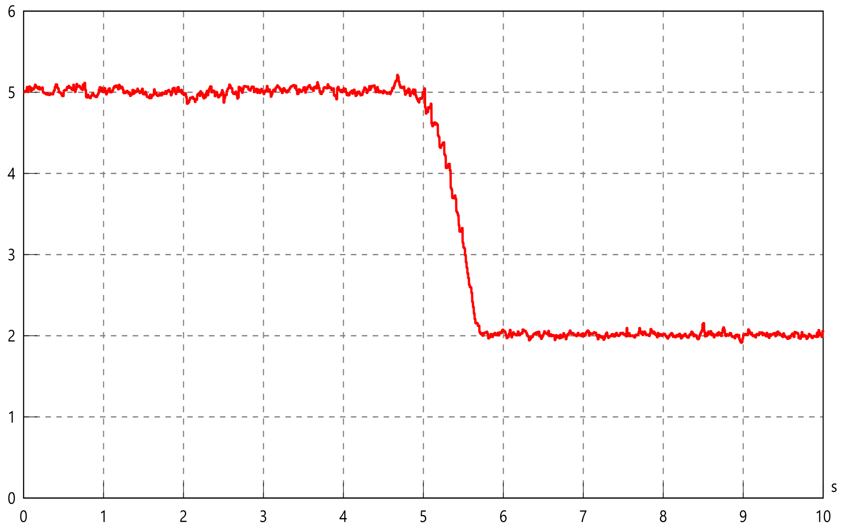
Local Estimator

Particle Filter

- Unlike the recursive least squares estimator, this algorithm is suitable for estimating the parameters of both linear and nonlinear systems.



Particle Filter Method

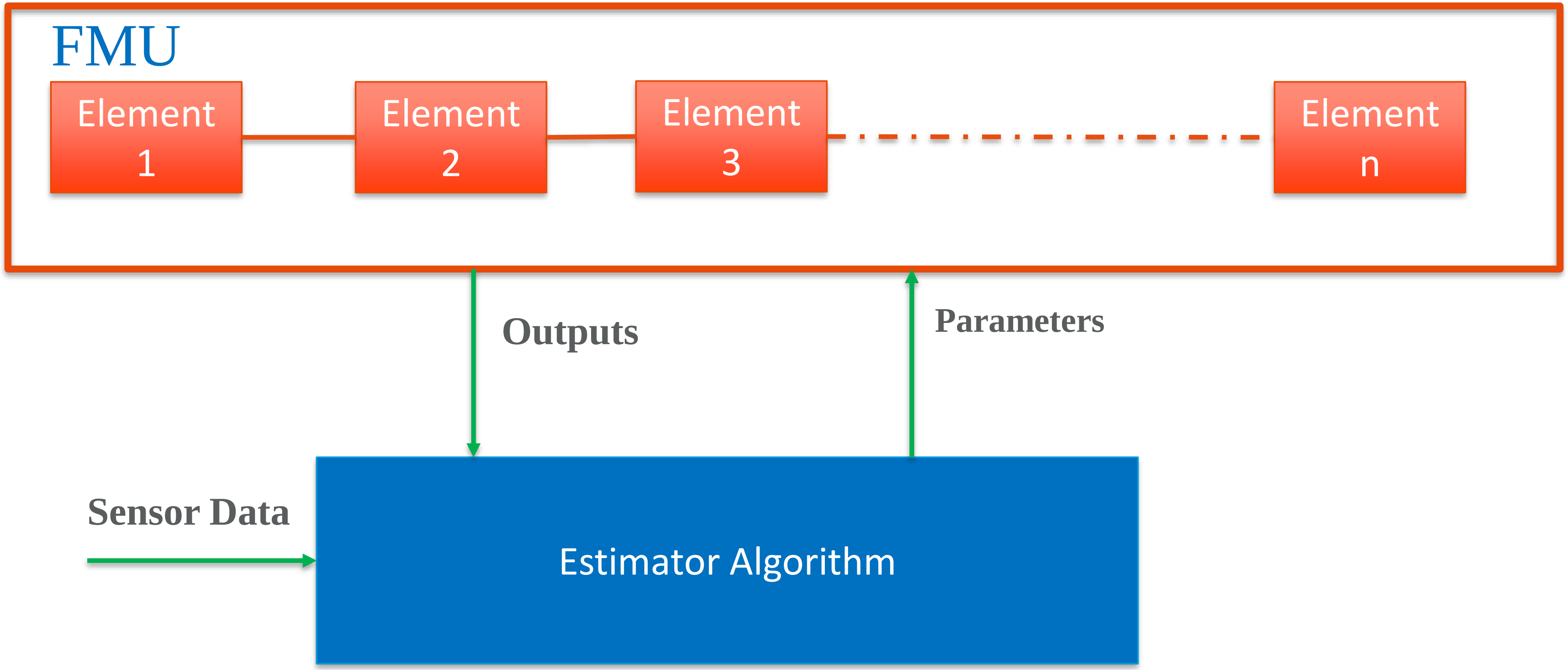


Mass of M1 as a function of time

- CPU-intensive in the case of large models.

Global Estimator

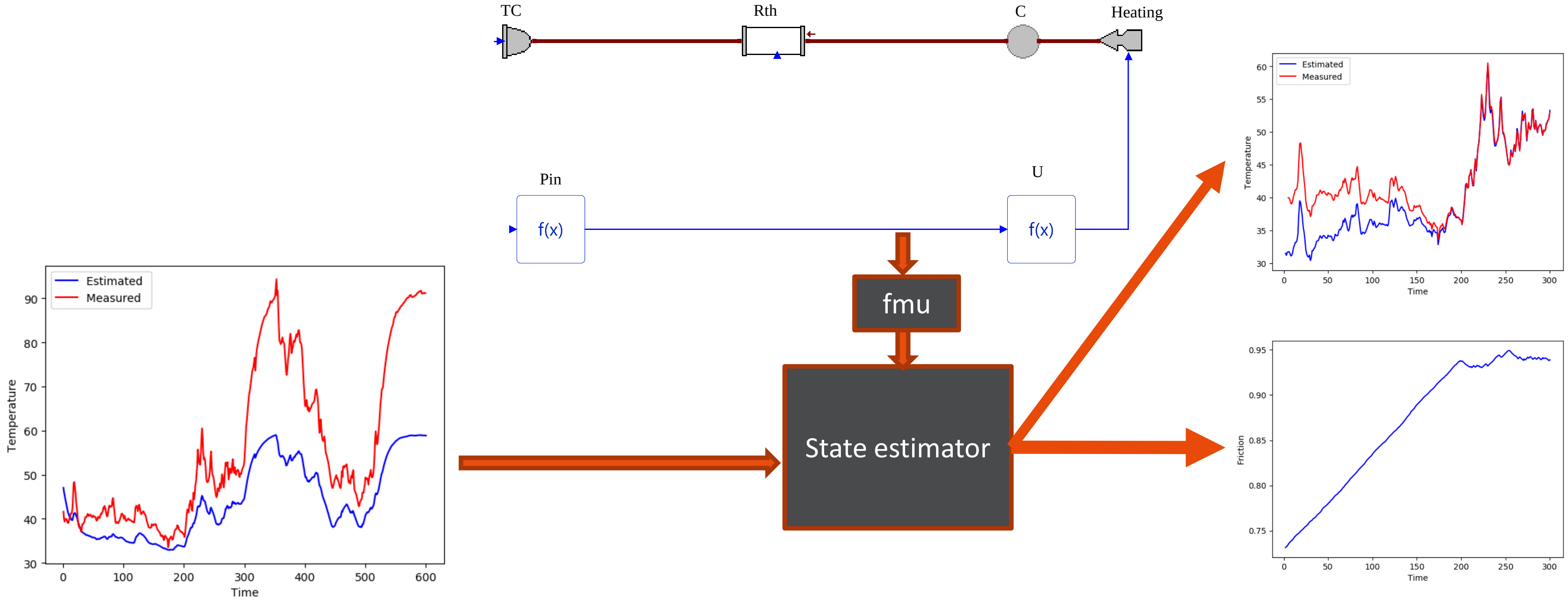
- The global estimator is implemented outside Modelica and uses the whole system model to estimate target parameters.



Global Estimator

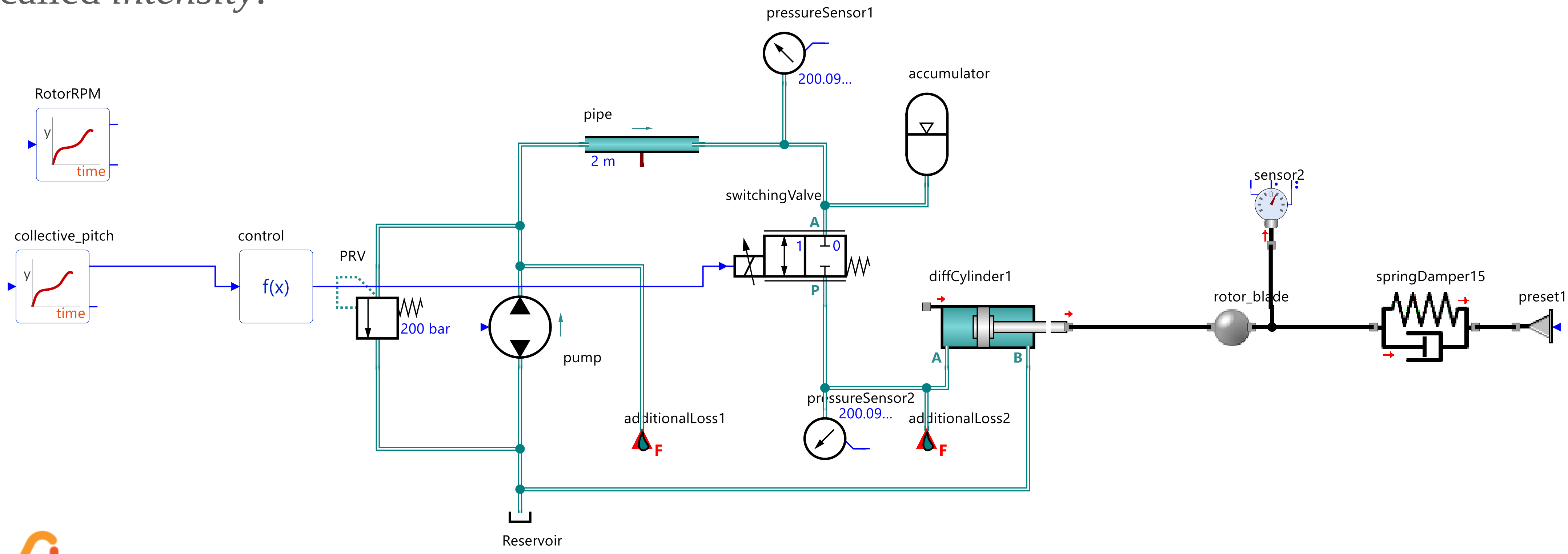
Particle Filter

- An example of using the state estimator for a thermal model of a wind turbine component.
- It can been seen from the output of the estimator that the friction in the system changed from 0.70 to 0.93.



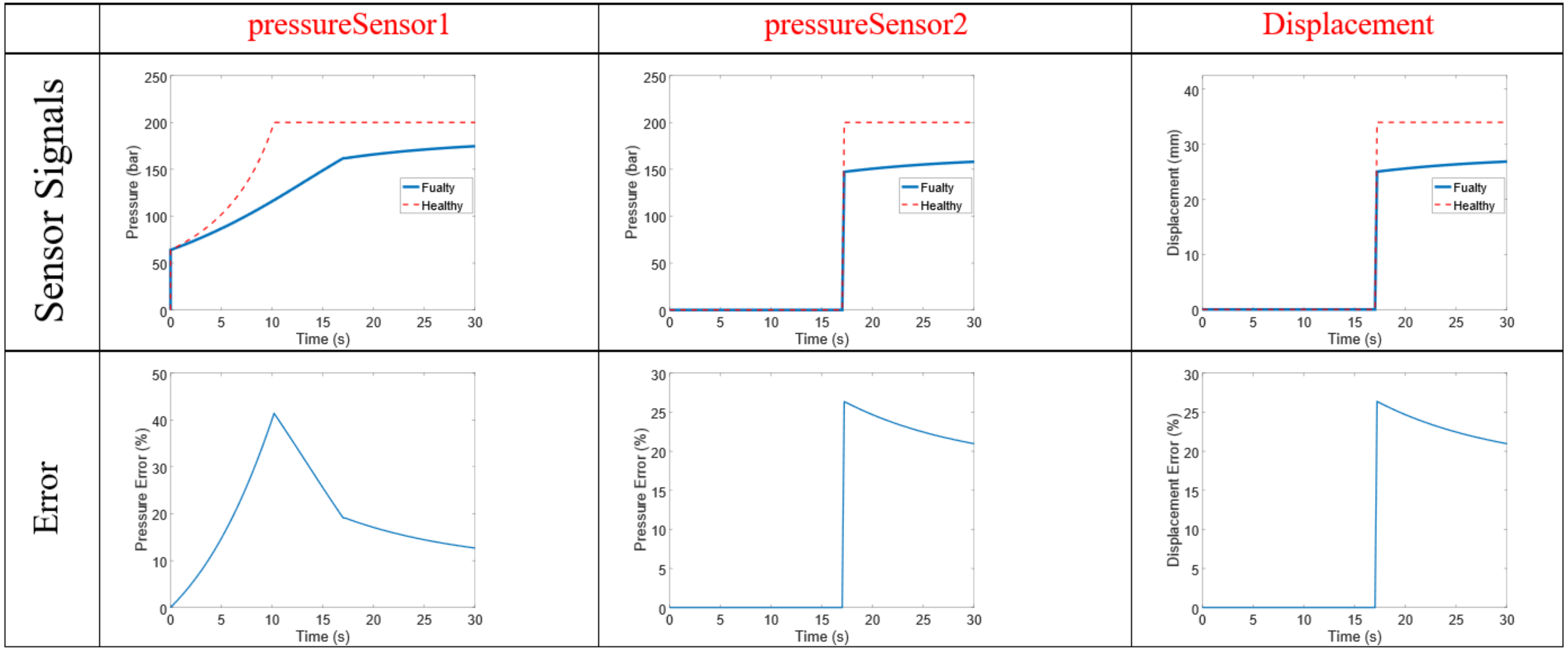
Fault Detection Using Multiple Sensors

- Our method is appropriate for multiple sensors and multiple faults.
- Example: model of a hydraulic system with two fault components and two pressure sensors and one displacement sensor.
- The amount of faults or leakages were controlled by a parameter inside the faulty components called *intensity*.



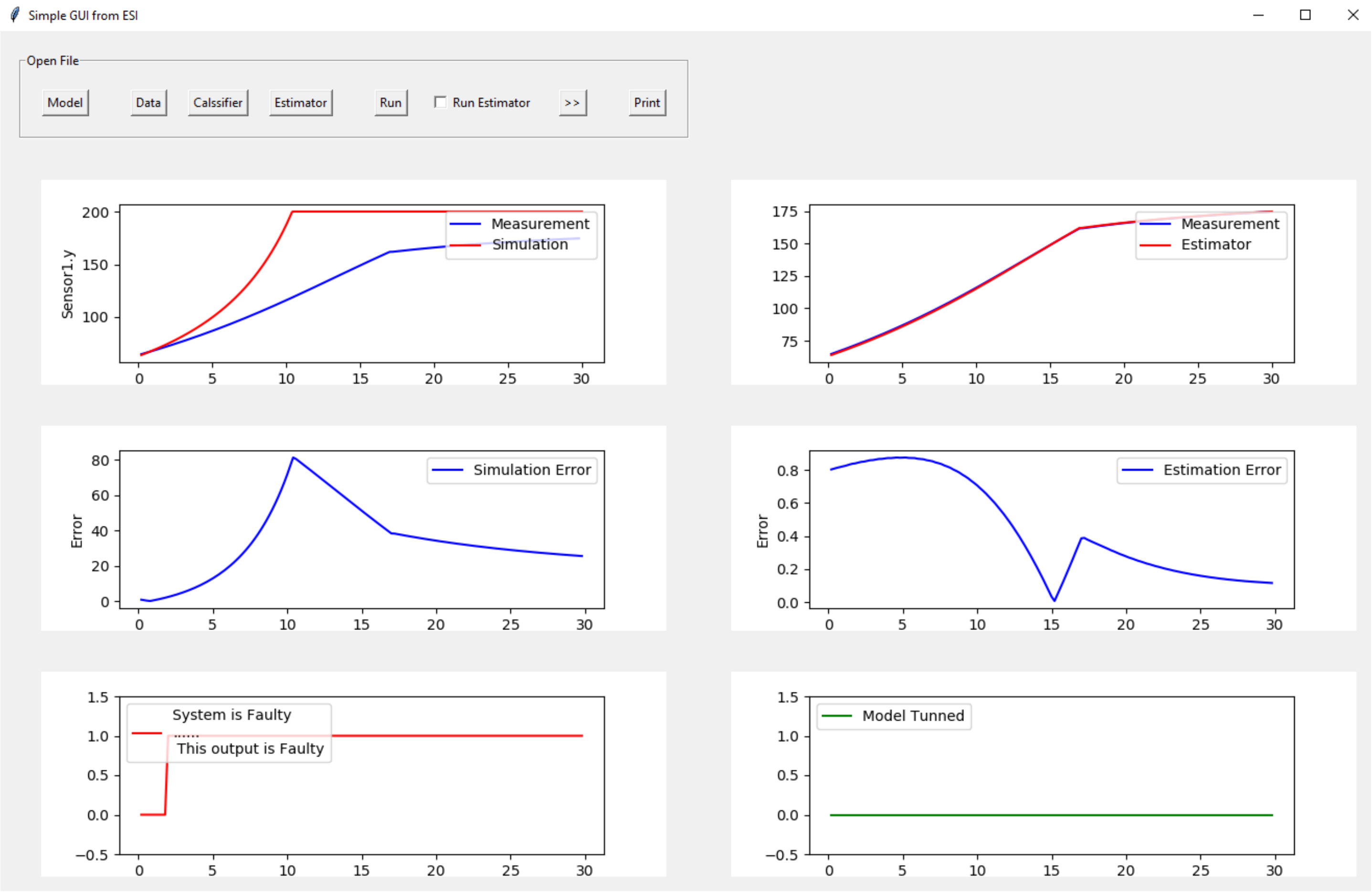
Fault Detection Using Multiple Sensors

- An experiment was performed to simulate the faulty system, with fault intensities 0.2 for both fault components.



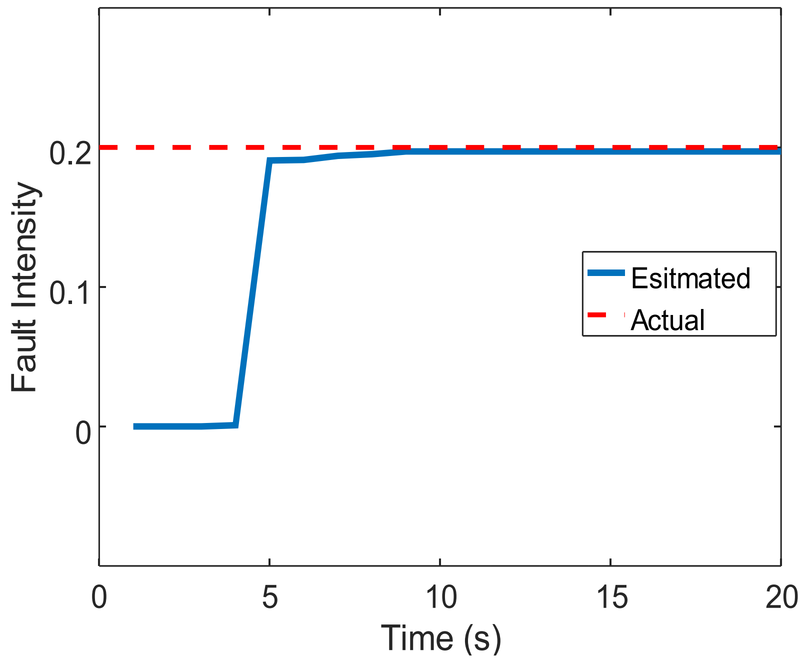
Fault Detection Using Multiple Sensors

- The particle filter algorithm tuned the fault parameters to minimize the error between the data from the sensors and simulation

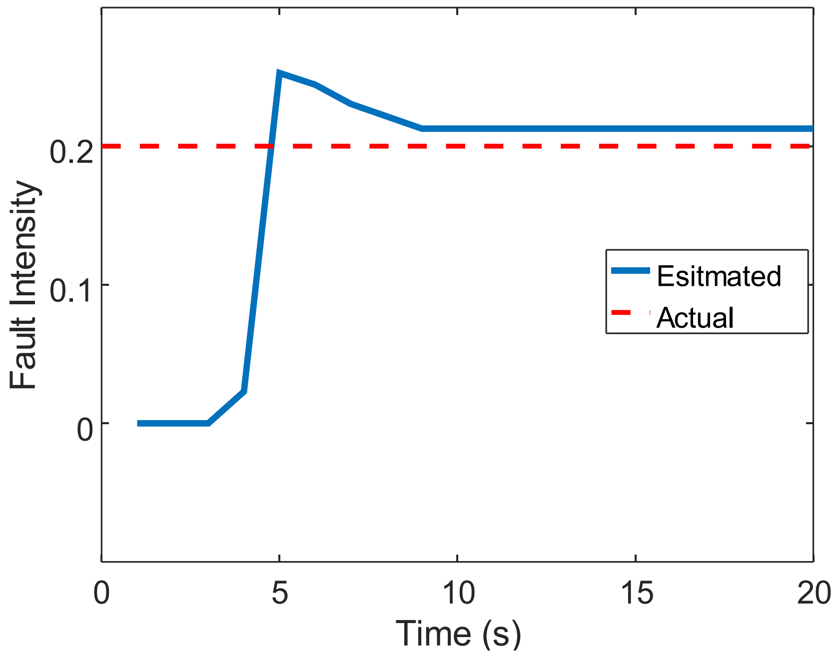


Fault Detection Using Multiple Sensors

- Using sensors enabled the state estimator to estimate both faults.



AdditionalLoss1



AdditionalLoss2

Conclusions

- We examined the applicability of two different types of estimation methodology (local and global).
- Different parameter estimation algorithms using Modelica and FMI have been considered.
- Systematic representation of fault using SRA library *.
- We demonstrated how these methods can be applied to use external stimuli, in this case thermal sensor data, to obtain an estimate of the health of a real system.

* A. Kolesnikov et al Systematic Simulation of Fault Behavior by Analysis of Vehicle Dynamics, Proceedings of the 13th International Modelica Conference 2019, doi: 10.3384/ecp19157451

Thanks