WORK PACKAGE 3.1

APPROACHES FOR DIAGNOSTICS AND PROGNOSTICS

CONTROL THEORY AND APPLICATIONS CENTRE
COVENTRY UNIVERSITY

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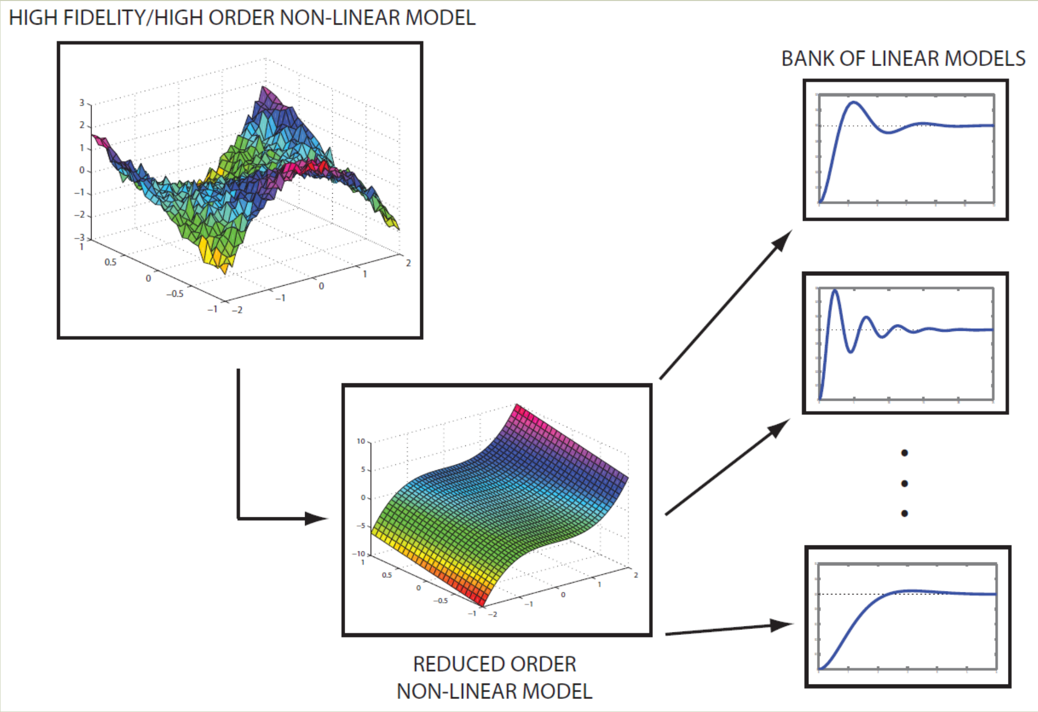
INTRODUCTION

- Aim – to reduce computational complexity of model yet retain sufficient accuracy for a specific purpose, i.e. control, diagnostics, prognostics

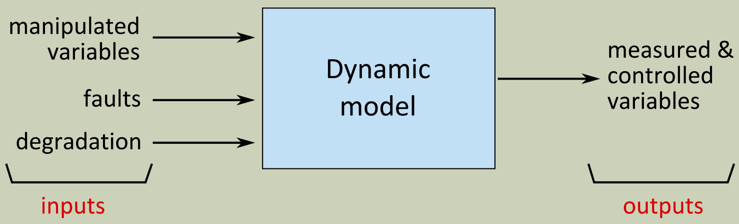


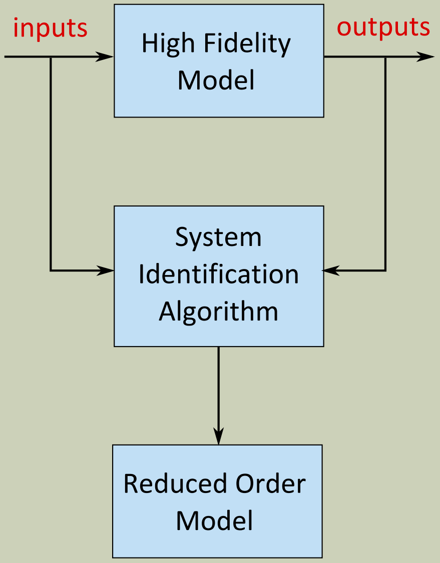
CONTENT

- Model based approach to diagnostics
- Case study: diagnosis of proton exchange membrane(PEM) fuel cell
- Fault diagnostics and prognostics – data driven approach
- Case study: bearing data remaining useful life (RUL) estimation

MODEL-BASED APPROACH FOR DIAGNOSTICS

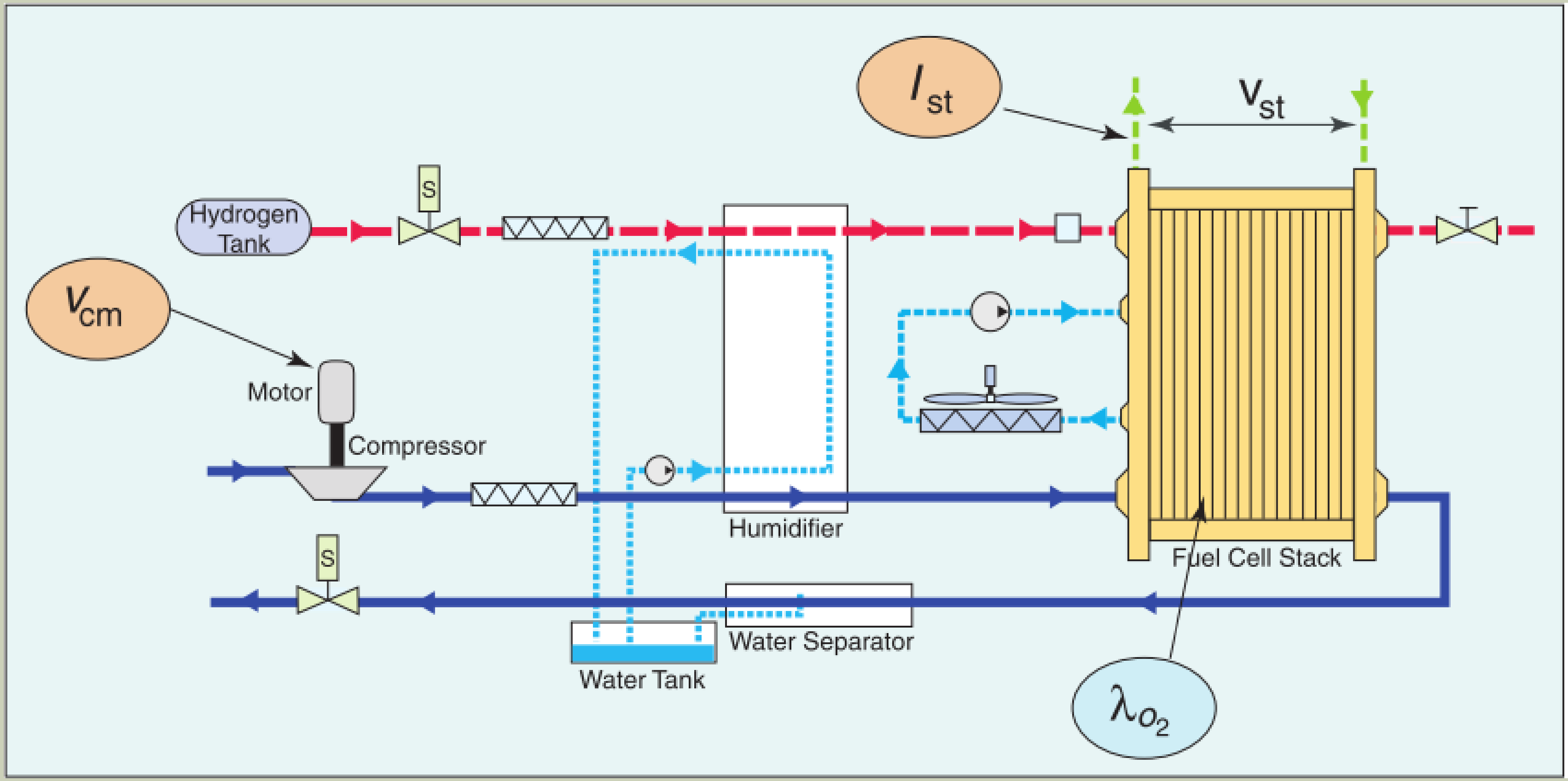
- Faults and degradation represented as additional inputs to the system





- High Fidelity Model used as a surrogate of real-world system
- Reduced order model identified from input and output data
- Fault detection and diagnosis filter designed to detect and identify faults and degradation

HIGH ORDER PEM FUEL CELL MODEL



J. Pukrushpan, A. Stefanopoulou, and H. Peng, “Control of fuel cell breathing,” IEEE Contr. Syst. Mag., vol. 24, no. 2, pp. 30–46, Apr. 2004.

FUEL CELL DIAGNOSTICS

- Multiple-input multiple-output model:
  - **Inputs:** stack current and compressor voltage
  - **Outputs:** net power, stack voltage, excess oxygen ratio (oxygen flow into cathode/oxygen reacted)
  - **Induced faults:**
    - Actuator fault – variation in compressor voltage/efficiency simulating surge/choke affecting air flow to the supply manifold
    - Supply manifold fault – variation of supply manifold pressure to represent air leakage
    - Fuel cell stack fault – cathode exit flow rate blockage to simulate flooding
- Steady state feed-forward controller for compressor voltage to maintain oxygen excess ratio of 2

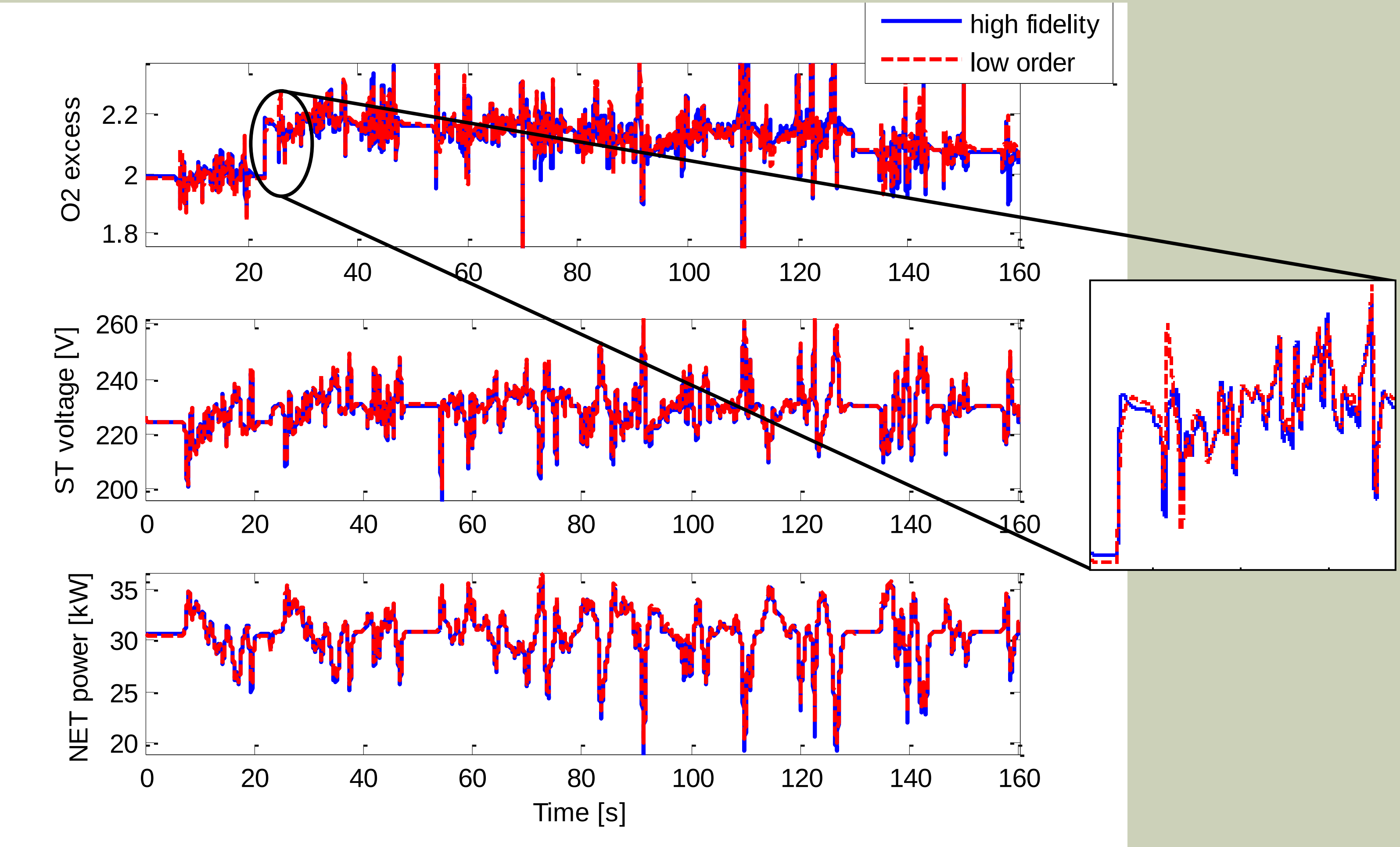
FUEL CELL DIAGNOSTICS

- Response of reduced order model

$R_T^2 = 92.0$

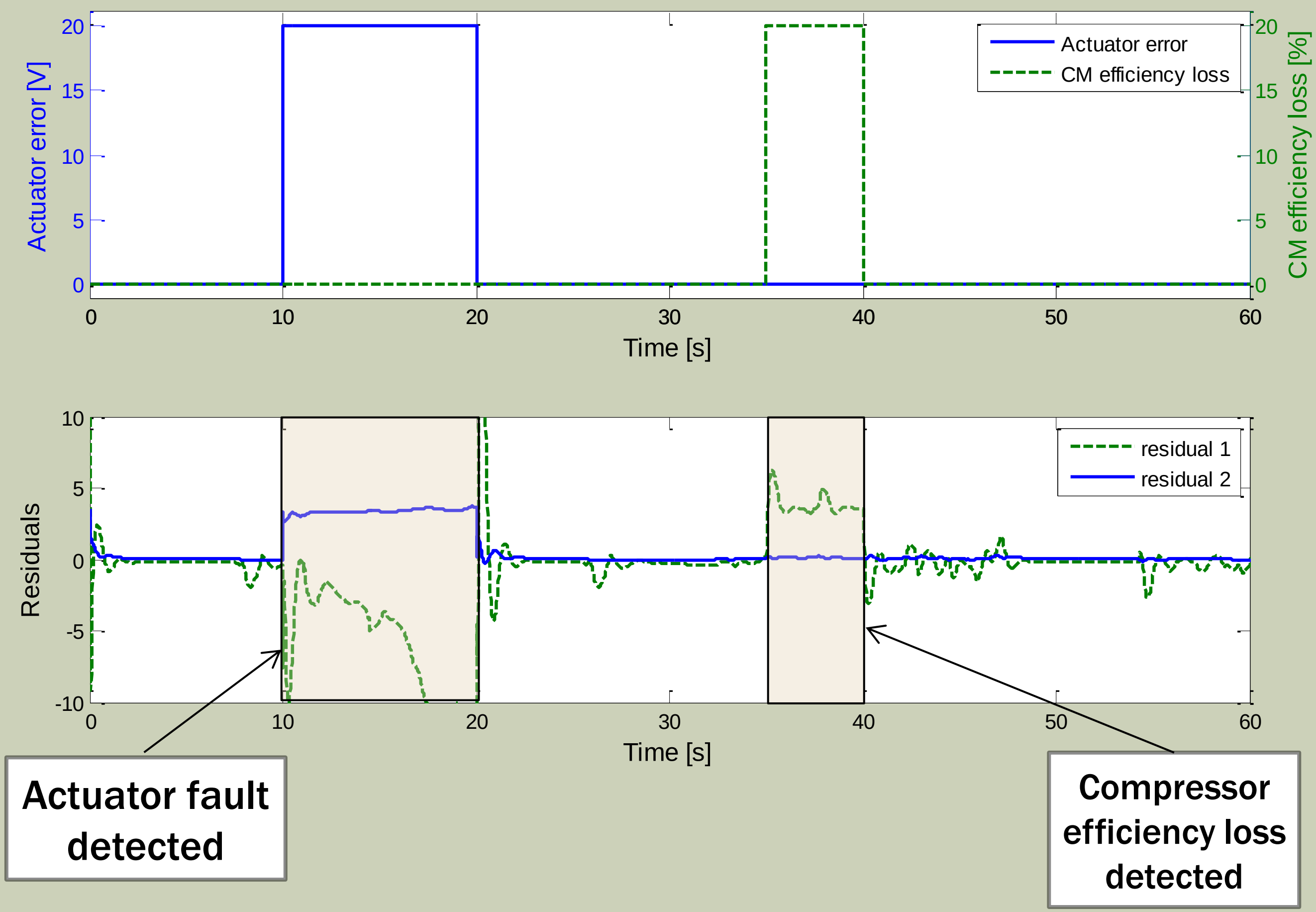
$R_T^2 = 99.0$

$R_T^2 = 99.3$

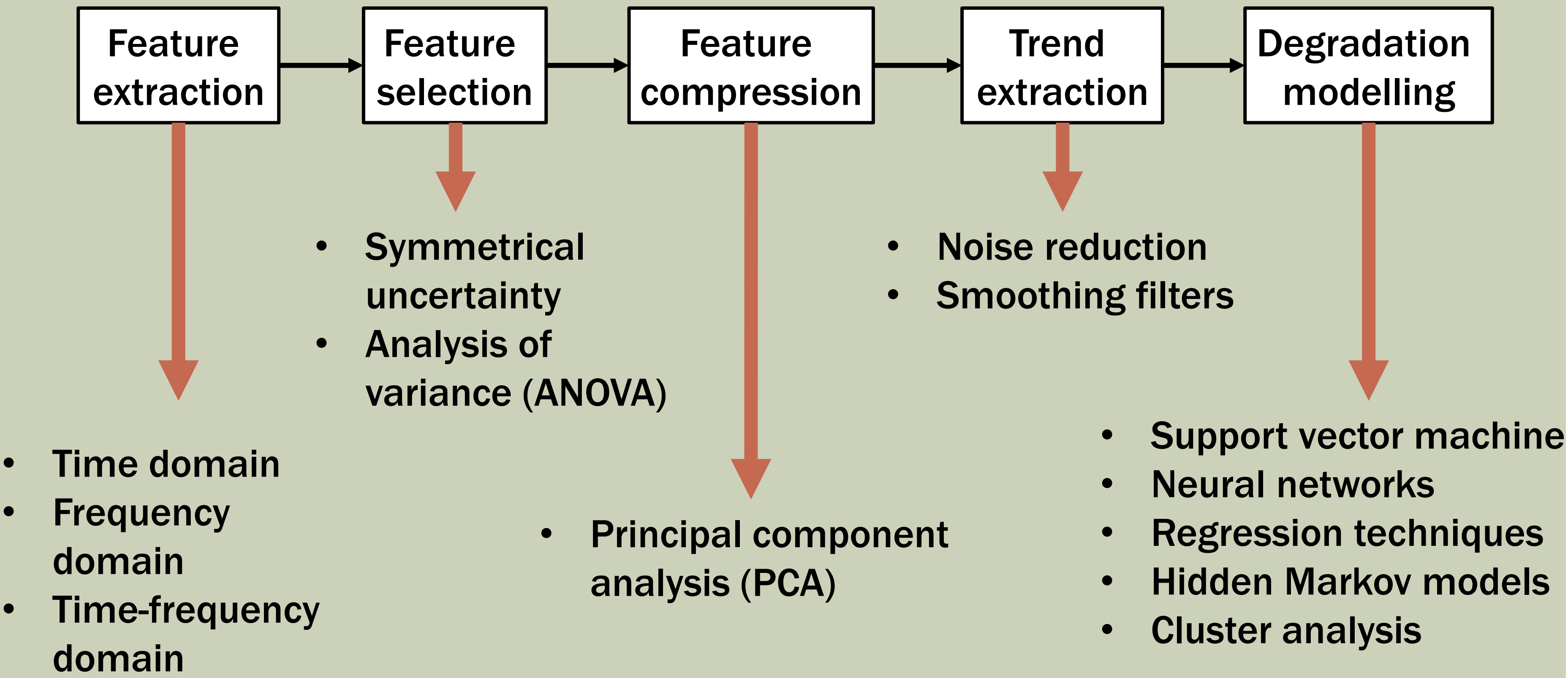


FUEL CELL DIAGNOSTICS

- Fault detection and isolation observer

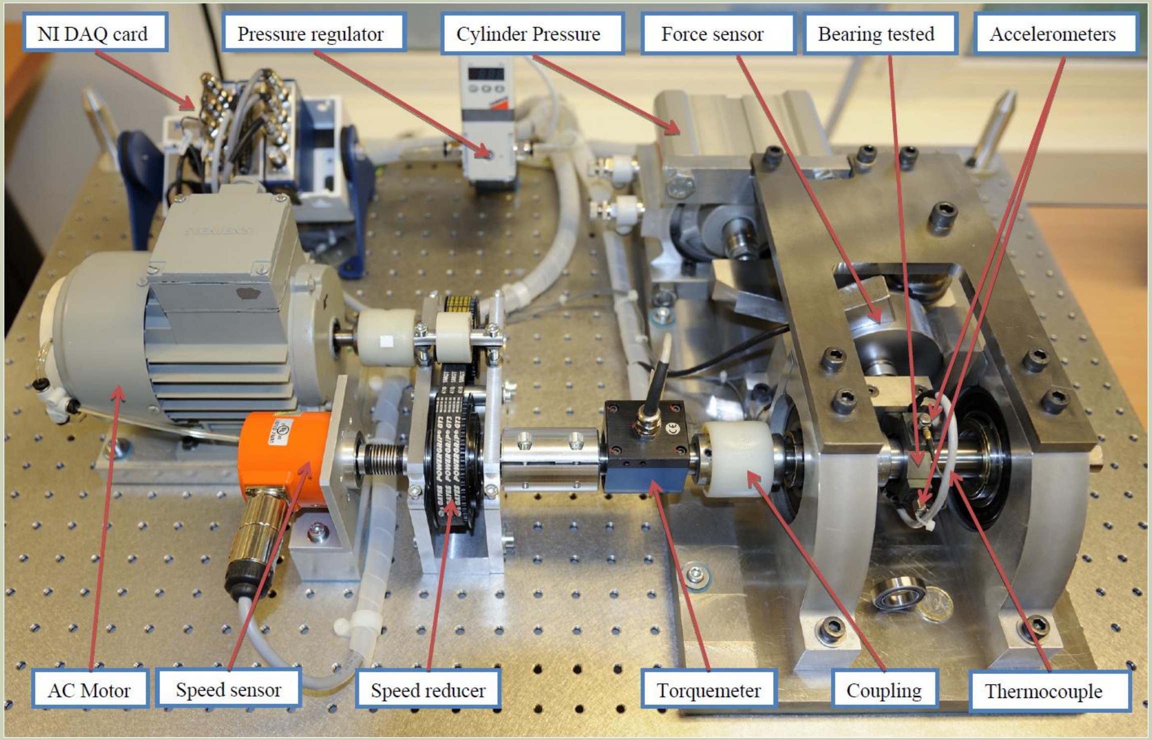


FAULT DIAGNOSTICS AND PROGNOSTICS – DATA DRIVEN APPROACH



BEARING DATA CASE STUDY

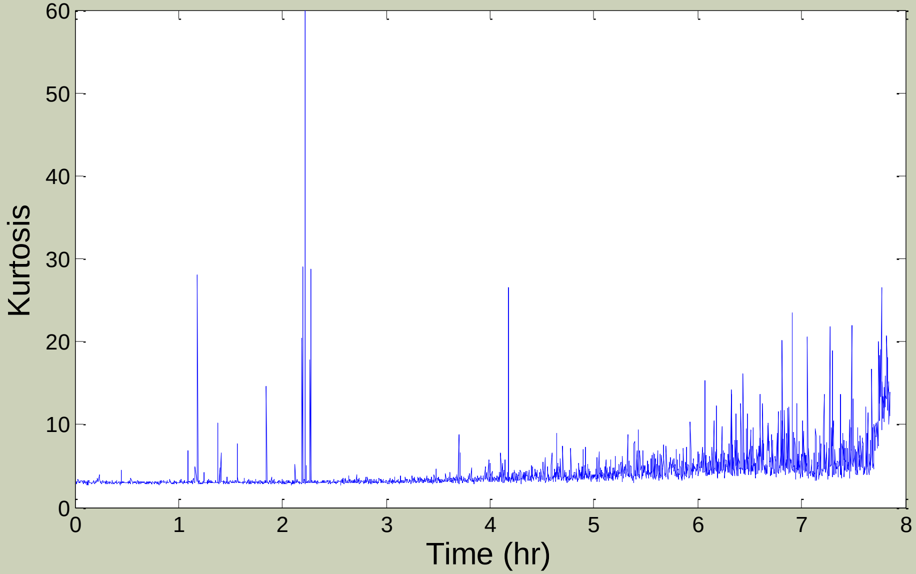
- PRONOSTIA experimentation platform: FEMTO-ST Institute
- Run-to-failure experiments

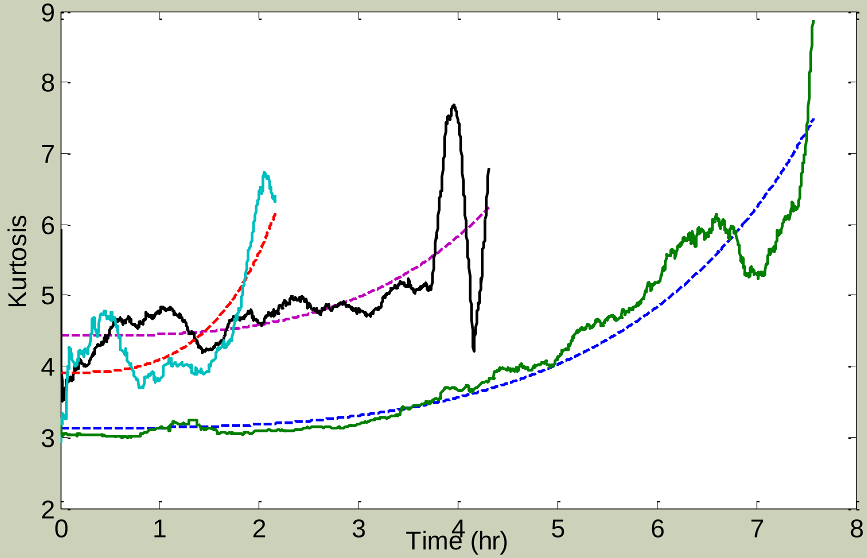


P. Nectoux, R. Gouriveau, K. Medjaher, E. Ramasso, B. Morello, N. Zerhouni, C. Varnier. PRONOSTIA: An Experimental Platform for Bearings Accelerated Life Test. IEEE International Conference on Prognostics and Health Management, Denver, CO, USA, 2012

KURTOSIS

- $\beta = \frac{\int_{-\infty}^{+\infty}(x-\bar{x})^4 P(x)dx}{\sigma^4}$
- **Undamaged bearing:** $\beta = 3$



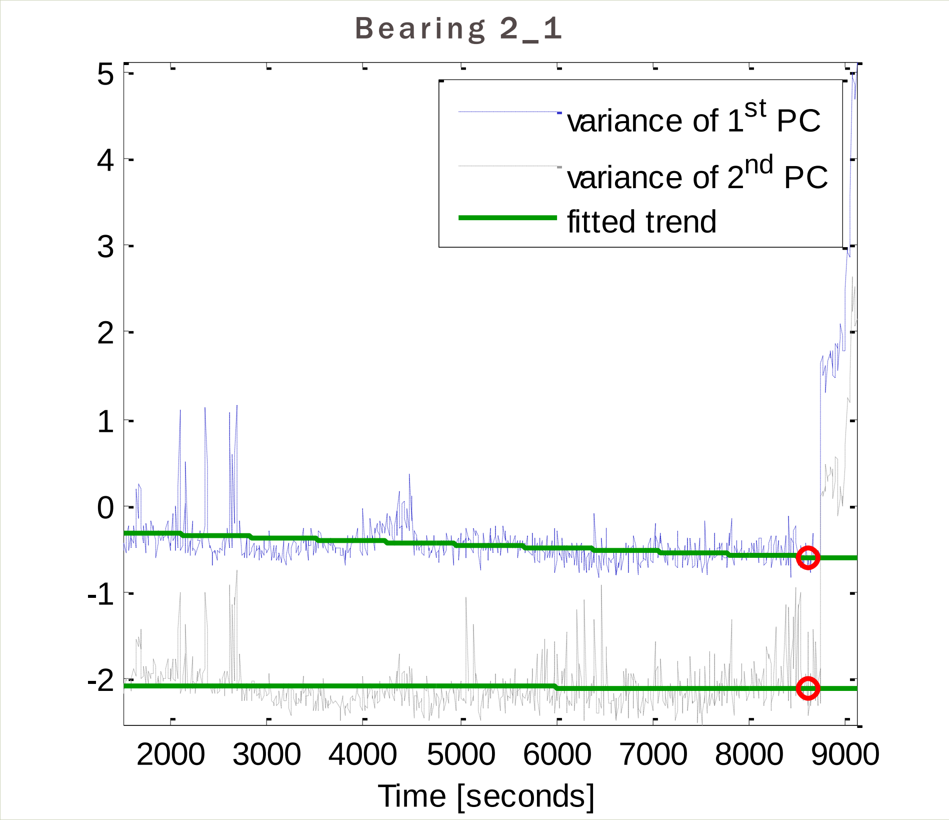


RUL MODELLING

- ***RUL modelling***
  - Variance of principal components of displacement exhibits descending trend until failure

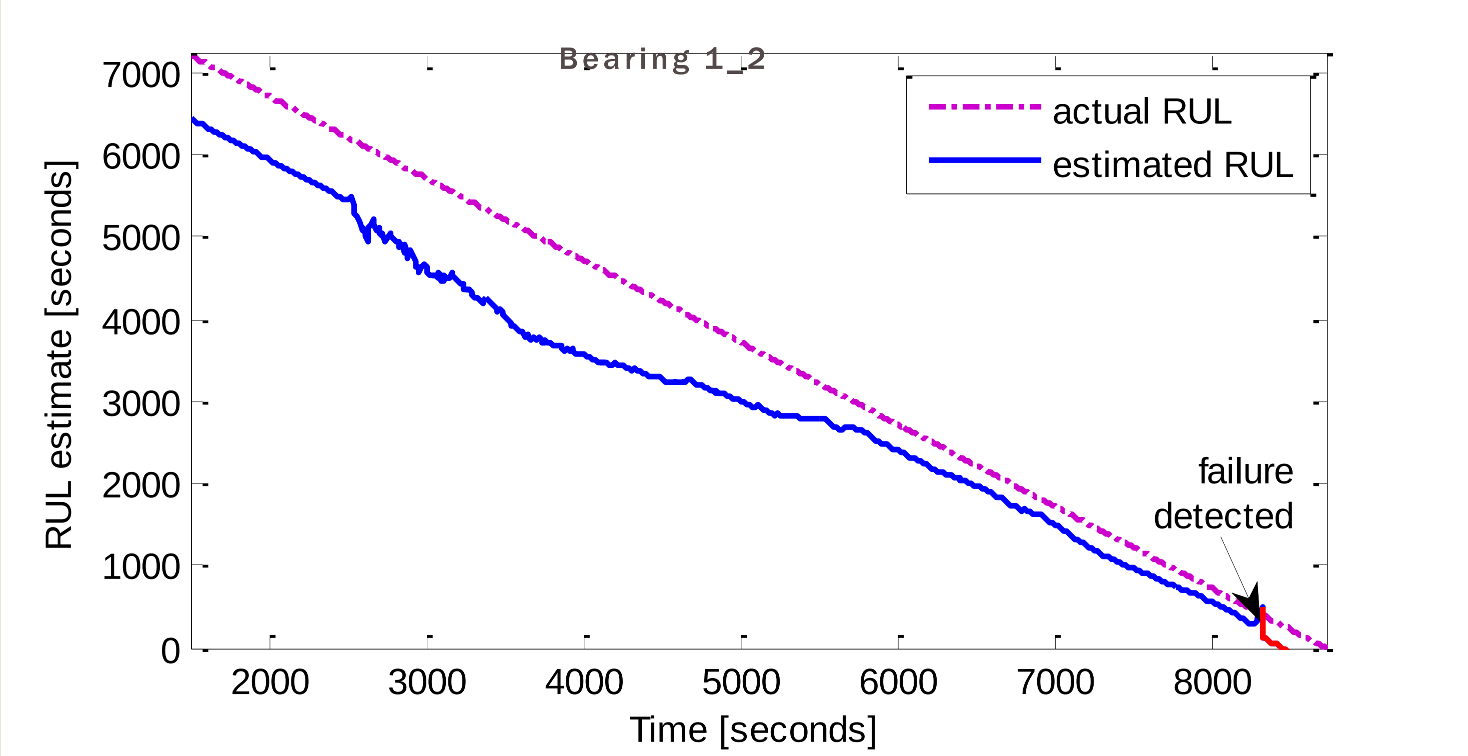
$$trend = a \cdot time + b$$

  - Analysed dependency between parameters a, b and bearing life



RUL MODELLING

- ***Estimated RUL***
  - 3 estimation data sets
  - 1 validation set



SUMMARY

- Knowledge and understanding of elements required for a unified approach to condition based maintenance framework
- Initial investigation of various methods for fault diagnostics and remaining useful life prognostics
- Fuel cell and rolling element bearings case studies used to examine and validate algorithms

Further work –

- Develop generalised set of algorithms for diagnostics and prognostics
- Demonstrate algorithms on additional case studies
- Investigate applicability for online implementation of reduced order models for control, diagnostics and prognostics