Meeting with Gregory Provan and Alexander Feldman

Erik Frisk

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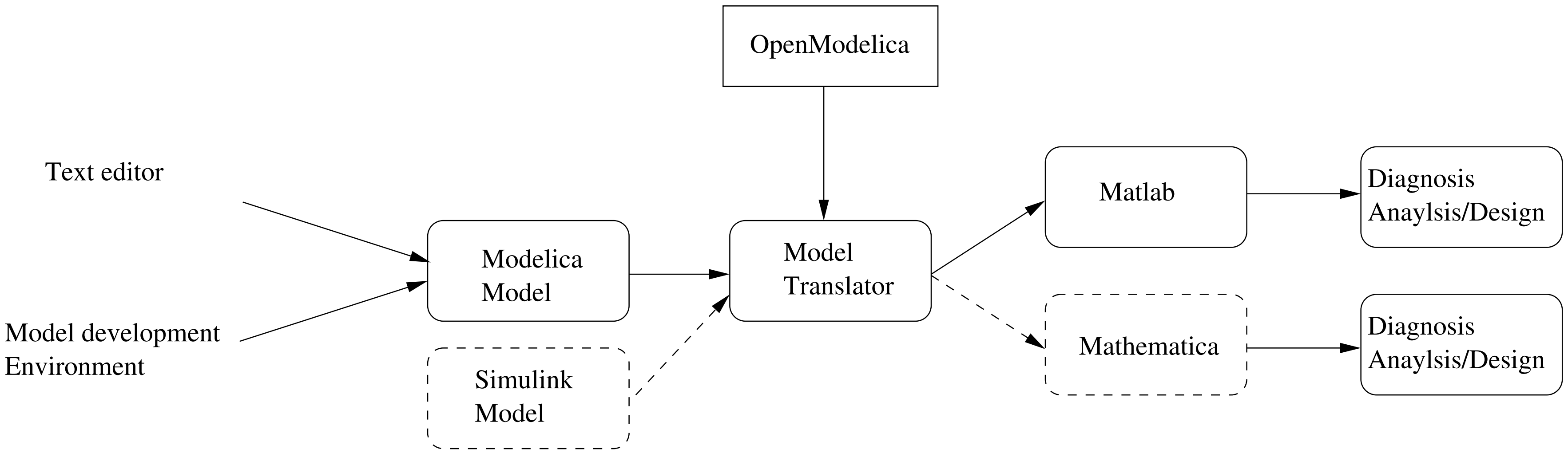
2013-02-06

Linköping University

Agenda and scope of this presentation

- Very brief outline of our activities in structural methods
- Modelica and Simulink, tool related research
- Leaves out many other parts of our research
- http:/www.fs.isy.liu.se/Publications/diagnosis.html
- http://www.fs.isy.liu.se/Software/

Structural analysis related tools at LiU



- Matlab
- Mathematica
- Simulink
- Modelica

- Simulink(/Modelica) to model structure/equations in Matlab
- MSO-algorithm/TestModTool (Matlab)
- Sensor placement; structural (Matlab), analytical (Mathematica)
- Isolability analysis; structural and analytical/quantitative (Matlab)
- Carl Svärd tools; Sequential residual generators from a Simulink model (Matlab)
- Automatic EKF code generation (Mathematica & C++/Matlab)
- ...

Brief summary: Tool development (for us) too time consuming for the scientific benefit. We have no well developed tools.

Finding redundant sets of equations

IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 38, NO. 1, JANUARY 2008 197

An Efficient Algorithm for Finding Minimal Overconstrained Subsystems for Model-Based Diagnosis

Mattias Krysander, Jan Åslund, and Mattias Nyberg

***Abstract*—In model-based diagnosis, diagnostic system construction is based on a model of the technical system to be diagnosed. To handle large differential algebraic models and to achieve fault isolation, a common strategy is to pick out small overconstrained parts of the model and to test these separately against** redundancy is low even if the models are large. The algorithm is applied to a Scania truck engine model with 126 equations. There were 1419 minimal overconstrained subsystems, and all of these were found with the new algorithm in less than half a

Efficient algorithm to find sets of equations that can be used to compute a residual/detection signal.

Sensor placement analysis

1398 IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 38, NO. 6, NOVEMBER 2008

Sensor Placement for Fault Diagnosis

Mattias Krysander and Erik Frisk

***Abstract*—An algorithm is developed for computing which sensors to add to meet a diagnosis requirement specification concerning fault detectability and fault isolability. The method is based only on the structural information in a model, which means that possibly large and nonlinear differential–algebraic models can be handled in an efficient manner. The approach is exemplified on a model of an industrial valve where the benefits and properties of the method are clearly shown.**

***Index Terms*—Fault diagnosis, fault isolation, sensor placement.**

I. Introduction

FAULT diagnosis and process supervision are an increasingly important topic in many industrial applications and also in an active academic research area. The nature of a model-based diagnosis system is highly dependent on the type of model that is used. For works based on continuous differential/difference-equation-based models (see, e.g., see [1] and [2] and the references therein for discrete-event models

The main objective of this paper is to develop an algorithm that, from a given model and a specified detectability and isolability performance specification, computes a characterization of all possible sets of sensors, which makes it possible to meet the requirement specification.

This paper is organized as follows. A formal problem formulation is presented in Section II. Section III gives a background of the theoretical tools used in the development of the method in Section IV. The algorithm[1] is then summarized in Section V and thoroughly exemplified on an industrial valve model in Section VI. Relations to other published related works are discussed in Section VII, and some conclusions are given in Section VIII.

II. Problem Formulation

Before the main objective of this paper is formally presented, a small example is discussed that illustrates the fundamental

Find sets of sensor locations that gives certain level of structural isolability performance

Automatica 45 (2009) 364–371

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ELSEVIER

Sensor placement for fault isolation in linear differential-algebraic systems☆

Erik Frisk*, Mattias Krysander, Jan Åslund

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ARTICLE INFO

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Keywords:
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ABSTRACT

An algorithm is proposed for computing which sensor additions make a diagnosis requirement specification regarding fault detectability and isolability attainable for a given linear differential-algebraic model. Restrictions on possible sensor locations can be given, and if the diagnosis specification is not attainable with any available sensor addition, the algorithm provides the solutions that maximize specification fulfillment. Previous approaches with similar objectives have been based on the model structure only. Since the proposed algorithm utilizes the analytical expressions, it can handle models where structural approaches fail.

Extend the structural results to analytical results to be able to reason about problems with structural analysis

Isolability analysis

1398 IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 38, NO. 6, NOVEMBER 2008

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Mattias Krysander and Erik Frisk

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1216 IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 42, NO. 5, SEPTEMBER 2012

Diagnosability Analysis Considering Causal Interpretations for Differential Constraints

Erik Frisk, Anibal Bregon, *Member, IEEE*, Jan Åslund, Mattias Krysander, Belarmino Pulido, *Member, IEEE*, and Gautam Biswas, *Senior Member, IEEE*

Abstract*—This paper is focused on structural approaches to study diagnosability properties given a system model taking into account, both simultaneously or separately, integral and differential causal interpretations for differential constraints. We develop a model characterization and corresponding algorithms, for studying system diagnosability using a structural decomposition that avoids generating the full set of system analytical redundancy relations. Simultaneous application of integral and differential causal interpretations for differential constraints results in a *mixed

In the last decade, a lot of work has been devoted to analyze diagnosability and sensor placement in the context of model-based diagnosis. Early works in the DX community on fault diagnosability were devoted to the definition and characterization of the diagnosability concept, based on fault detection and isolation results [8]. Recently, the process has been carried out by precomputing the whole set of existing analytical redundancy

Analyze isolability properties of a given model, results from sensor placement papers.

Extended to dynamic systems

Isolability analysis with quantified performance

A method for quantitative fault diagnosability analysis of stochastic linear descriptor models ⋆

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Abstract

Analyzing fault diagnosability performance for a given model, before developing a diagnosis algorithm, can be used to answer questions like "How difficult is it to detect a fault f_i?" or "How difficult is it to isolate a fault f_i from a fault f_j?". The main contributions are the derivation of a measure, *distinguishability*, and a method for analyzing fault diagnosability performance of discrete-time descriptor models. The method, based on the Kullback-Leibler divergence, utilizes a stochastic characterization of the different fault modes to quantify diagnosability performance. Another contribution is the relation between distinguishability and the *fault to noise ratio* of residual generators. It is also shown how to design residual generators with maximum fault to noise ratio if the noise is assumed to be i.i.d. Gaussian signals. Finally, the method is applied to a heavy duty diesel engine model to exemplify how to analyze diagnosability performance of non-linear dynamic models.

Key words: Fault diagnosability analysis, Fault detection and isolation, Model-based diagnosis.

(accepted for publication by Automatica)

Direct use of models in Modelica

Proceedings of ASME Turbo Expo 2013
GT2013
June 3-7, 2013, San Antonio, USA

GT2013-95727

FAULT TOLERANT SUPERVISION OF AN INDUSTRIAL GAS TURBINE

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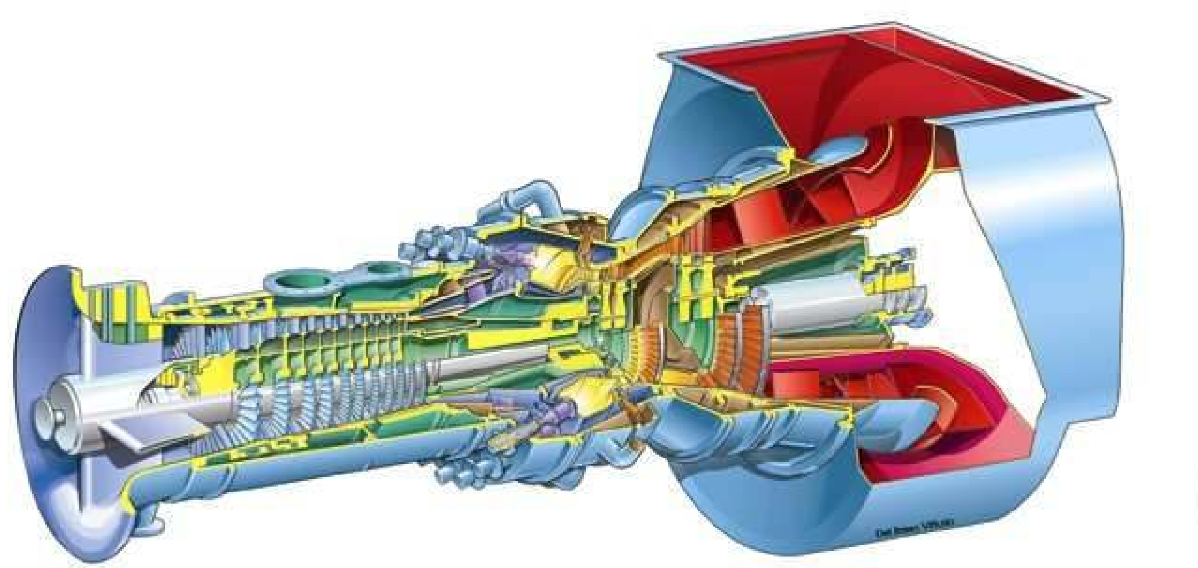
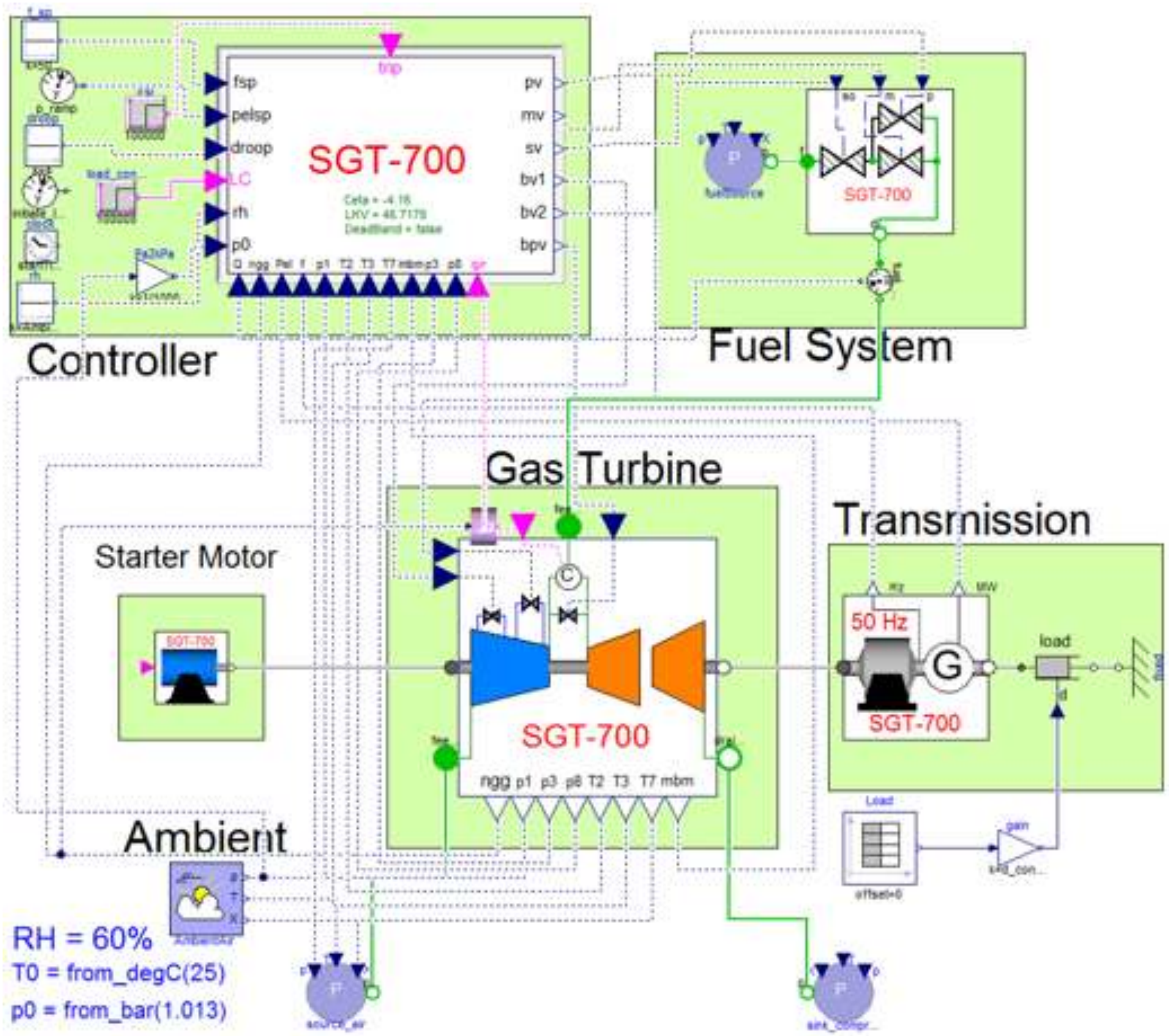
ABSTRACT
Supervision of the performance of an industrial gas turbine is important since it gives valuable information of the process health

presented. The major contribution of degradation mechanisms in an industrial gas turbine is *fouling*. The fouling is caused by small particles and contaminants in the air that are caught by the

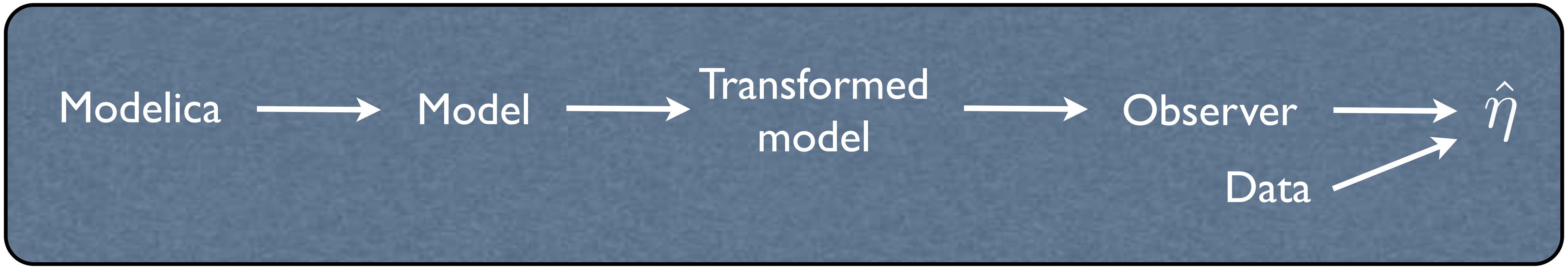


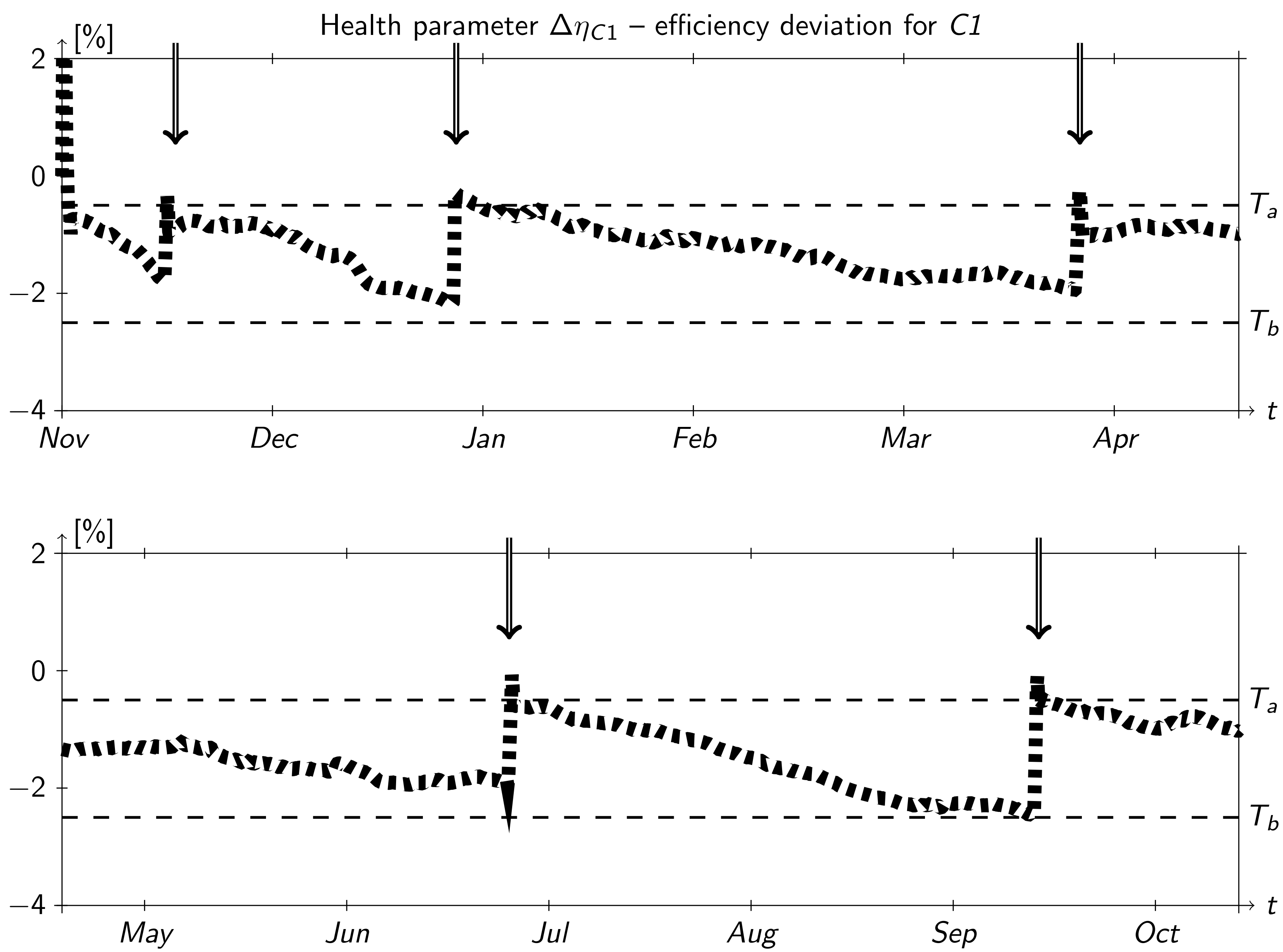
Gas Turbine Model



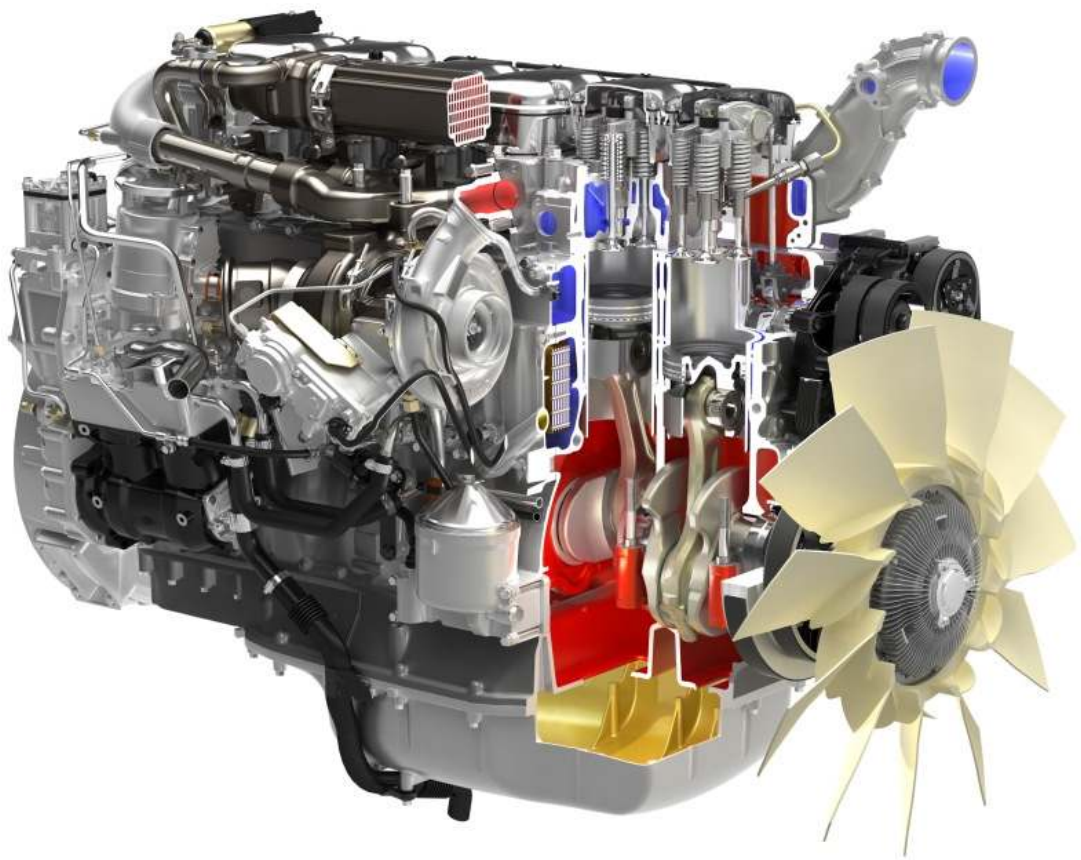
- Model in Modelica, 1000 equations for the gas turbine alone
- About 30-35 dynamic states
- Monitor the degree of efficiency in compressors, turbines, sensors, ...

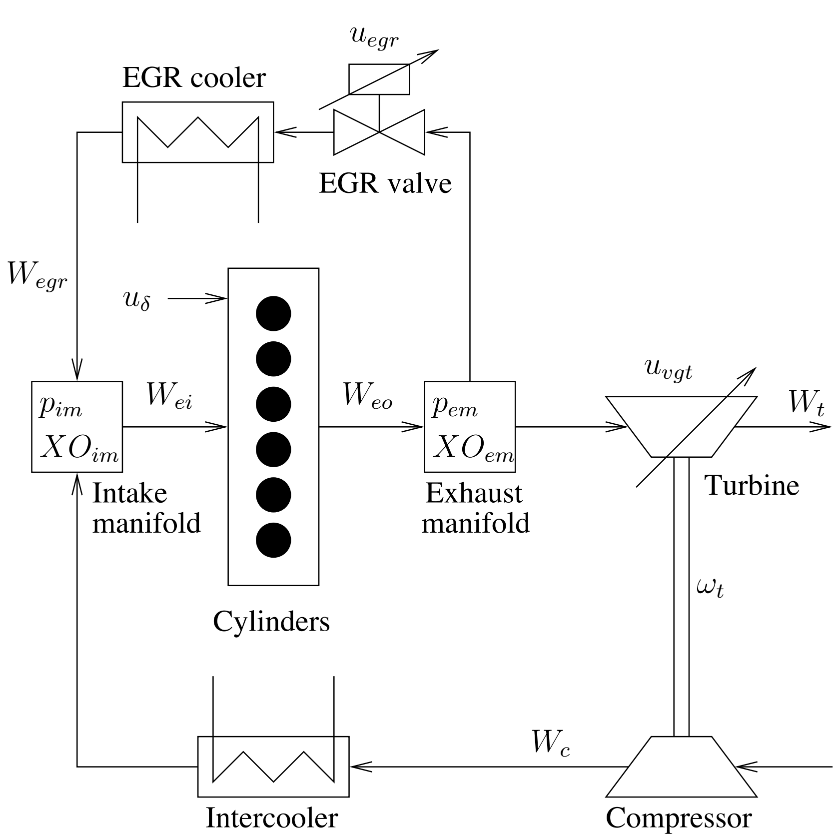
Modelica to diagnostic algorithm

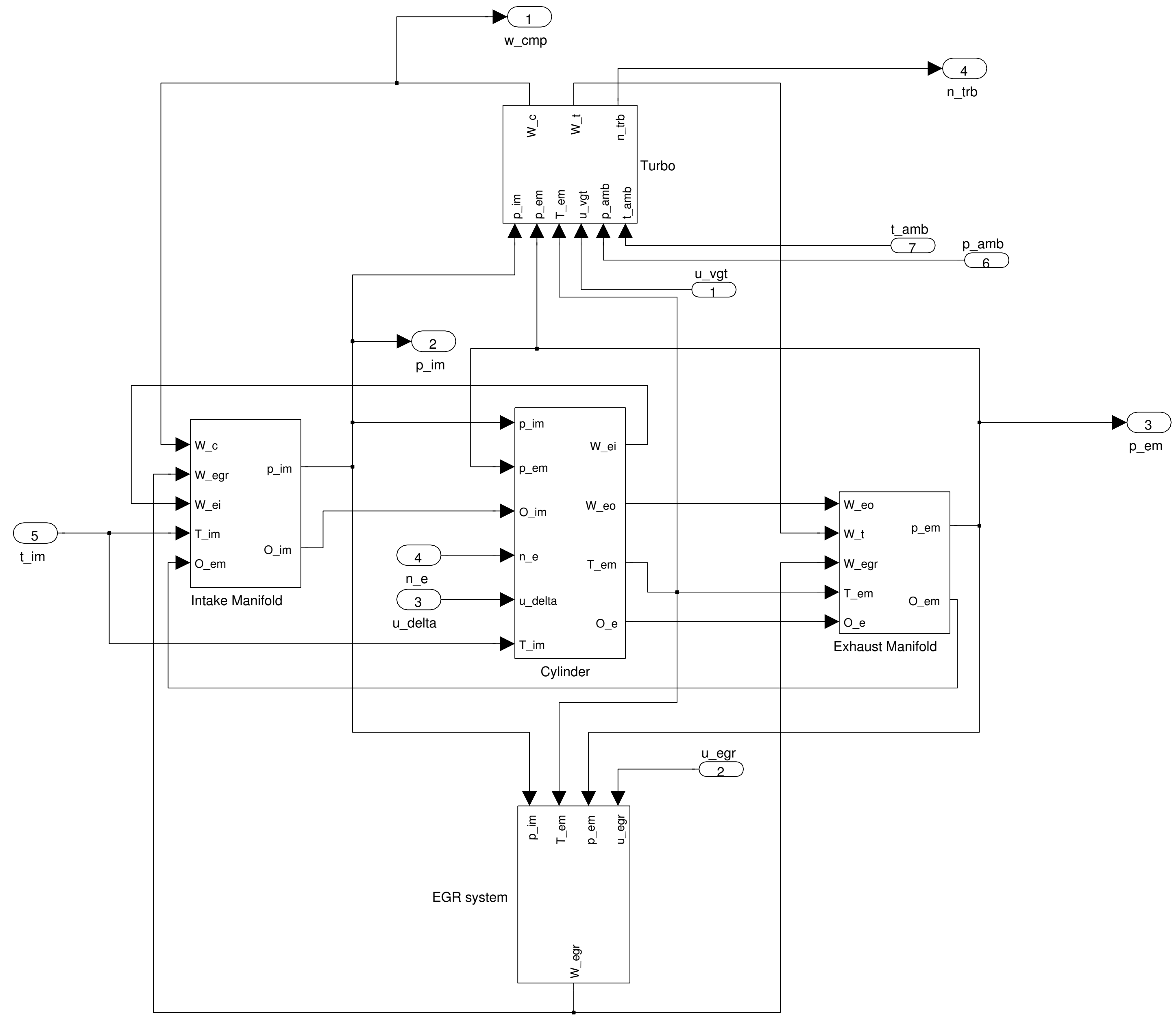




Simulink to Structural model - analysis and design







Matlab demo of isolability analysis possible
if there is interest

Sequential Residual Generation

Control Engineering Practice 21 (2013) 455–472

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Control Engineering Practice

journal homepage: www.elsevier.com/locate/conengprac

Automotive engine FDI by application of an automated model-based and data-driven design methodology

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ABSTRACT

Fault detection and isolation (FDI) in automotive diesel engines is important in order to ac
guarantee low exhaust emissions, high vehicle uptime, and efficient repair and maintenance.
illustrates how a set of general methods for model-based sequential residual generation
driven statistical residual evaluation can be combined into an automated design methodo
automated design methodology is then utilized to create a complete FDI-system for an a

1310 IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 40, NO. 6, NOVEMBER 2010

Residual Generators for Fault Diagnosis Using Computation Sequences With Mixed Causality Applied to Automotive Systems

Carl Svärd and Mattias Nyberg

***Abstract*—An essential step in the design of a model-based diagnosis system is to find a set of residual generators fulfilling stated fault detection and isolation requirements. To be able to find a good set, it is desirable that the method used for residual generation gives as many candidate residual generators as possible, given**

the first step, a large number of candidate residual generators are found, and in the second step, the residual generators most suitable to be included in the final diagnosis system are picked out. Since different residual generators have different properties

1

Selecting and Utilizing Sequential Residual Generators in FDI Applied to Hybrid Vehicles

Christofer Sundström, Erik Frisk, and Lars Nielsen

***Abstract*—For a realistic model of a complex system there will be thousands of possible residual generators to be used for diagnosis. Based on engineering insights of the system to be monitored, certain algebraic and dynamic properties of the residual generators may be preferred, and therefore a method for finding sequential residual generators has been developed that**

is based on computation sequences of the unknown variables [6], and is called sequential residual generators by [7]. To this method, one would like to add engineering insights where intuition regarding noise properties may make a dynamic computation sequence leading to integration preferable compared to

Accepted for publication in IEEE SMC-A

IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 42, NO. 2, MARCH 2012 371

Fault Diagnosis Based on Causal Computations

Albert Rosich, Erik Frisk, Jan Åslund, Ramon Sarrate, and Fatiha Nejjari

***Abstract*—This paper focuses on residual generation for model-based fault diagnosis. Specifically, a methodology to derive residual generators when nonlinear equations are present in the model is developed. A main result is the characterization of computation sequences that are particularly easy to implement as residual generators and that take causal information into account. An efficient algorithm, based on the model structure only, which finds all such computation sequences, is derived. Furthermore, fault detectability and isolability performances depend on the sensor configuration. Therefore, another contribution is an algorithm,**

a potential to increase diagnosis performance by using more advanced methods.

Many methods are difficult to use for industrial systems since the models typically include nonlinearities such as lookup tables, saturation, and hysteresis functions. There exist methods for dealing with such models [5]–[7], but they can often be practically infeasible. For example, methods based on variable elimination suffer from severe complexity problems, and Gröbner basis techniques fail for even moderately sized systems

Meeting with Gregory Provan and Alexander Feldman

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