Modelling Methods, Control Design and Diagnostics Applications in the Distributed Control Systems

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***Abstract*— This paper contains a review of modelling methods, control design and diagnostics methods to the systems with distributed architecture. Paper includes review of the worldwide research in modelling, control design and fault diagnostics of the simulation models and the real processes. It includes a lot of many approaches to modelling of the systems which are a part of the Distributed Control Systems. Also are presented possible methods of control design and fault detection in the levels of the Distributed Control Systems.**

***Keywords*—Distributed control system, modelling, experimental identification, control design, adaptive control, predictive control, fault diagnosis, assembly lines.**

I. Introduction

Distributed control systems (DCS) are complex systems built from many parts arranged in the levels from the lowest part, represented by real processes and models to the higher management part. Every level of the DCS can be described by some model. For the aims of my PhD. thesis are important models of the real processes. The model of the real process is a base of the control design. Implementation of the designed controller with the real process in correct control structure provides new quality of the system. However control provides the required quality of the DCS, sometimes may occurs some type of fault on the one or more real processes. Fault detection is research of fault diagnostics methods. All of these methods are usually used and implemented at the lower levels of the DCS [1], [2].

DCS provides a good opportunity for different kinds of modeling approaches, because this system includes continuous or discrete-event processes in continuous or discrete time form. There are many different methods of modelling and one of them is chosen by structure of the system. Different methods of system modelling are presented in [3] – [6].

Models of the real processes are used for next topic my PhD. thesis which is control and fault diagnosis design. Some interesting methods of the control design and diagnostics are presented in [7] – [16]. Usually control and fault diagnostics methods are interconnected, mainly in a real processes. Some of these methods can be implemented and verified on the simulation models and after successful verification used in real processes.

Modelling, control design and diagnostics implementation to the chosen simulations models are one of the main aims of my PhD. thesis. After successful testing and verification of control and diagnosis algorithms in simulation level will be these algorithms implemented to the real laboratory models.

All these facts presented in introduction are described in this paper.

II. DCS Architecture

DCS are created by many systems with the different manners. This fact causes different approaches to their modelling, control and diagnostics. Modeling, control and diagnostics are the aim of my PhD. thesis *Modern Methods of Modelling, Control and Diagnostics of Mechatronics Systems*. DCS provides a very good opportunity for study and application of different modelling, control and diagnostics algorithms. The DCS infrastructure of DCAI FEEI is presented in web page of Center of Modern Control Techniques and Industrial Informatics (*http://kyb.fei.tuke.sk/laben/infdsr.php*).

DCS architecture of DCAI, FEEI includes 5 levels, Fig. 1. The lowest level is the Technological level which includes real models, sensors and actuators. From many different models, for PhD. thesis are mainly important model of Ball and Plate, model of Hydraulics, model of Helicopter and Assembly lines (Flexible manufacturing System, Flexible Assembly Company).

The first level is Technological level of control and regulation. This level represents a set of sources for regulation and control based on programmable logic controllers (PLC) and technological PC's. Model sensors and actuators are connected to PLC's or technological PC's. For control of the Assembly lines and Hydraulic model are used PLC's. Helicopter model and Ball and Plate model are controlled by PC (interface between Helicopter model and PC is Lab Card; interface between Ball and Plate and PC is single-chip microcomputer).

The second level includes SCADA/HMI and simulation models of low level systems. SCADA/HMI supports supervisory control as well as the acquisition, collection and archivation of data from the low level processes. This level also includes simulation models which are very useful for modelling, control and diagnostics design for models in the lowest level of DCS.

The simulation models will be serving as the first step in control and diagnostics algorithms design. The partial aim of

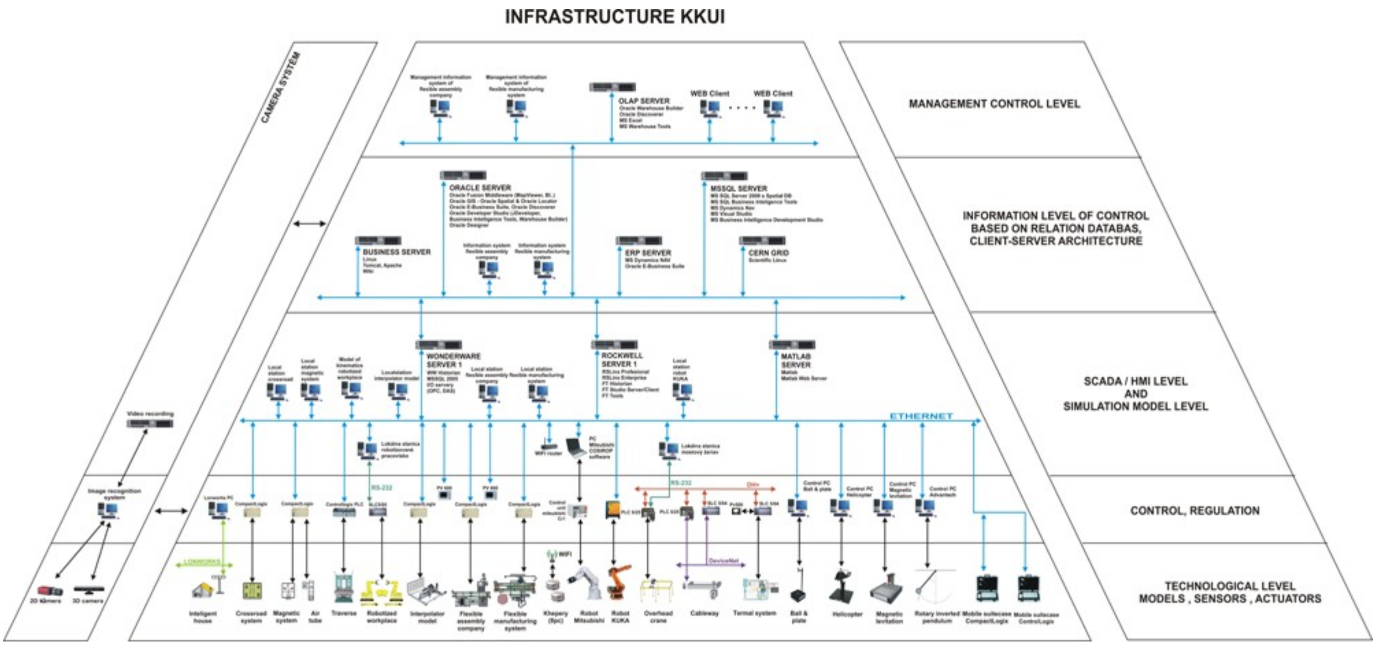

Fig. 1 Distributed Control System of DCAI, FEEI (http://kyb.fei.tuke.sk/laben/IMG/infsys.jpg)

my PhD. thesis is testing and verification of these algorithms on simulation models.

Next levels are Information level of control based on relational database system including MES and ERP/MRP. The last Management control level is based on multidimensional databases and OLAP technology. These levels are included in the paper for completeness of the DCS structure in this paper, but the main interests of this paper are in the Technological, Control and SCADA/HMI with simulation models level.

III. Systems Modelling at the Technological Level of DCS

Very important for aims of the PhD. thesis is choose suitable physical systems. These systems can be classified into [17]:

- continuous states
- discrete-event

systems and models of both systems can be realized in:

- continuous time
- discrete time

form.

The first category includes models of the systems with continuous states. These models can be modelling in continuous or discrete time form. For mathematical model derivation of these systems is possible to use theoretical modelling (analytical identification) or experimental modelling (experimental identification) [17], [18], [19].

Different kinds of the nonlinear systems models are shown in Fig. 2. Analytical and experimental identification includes many different methods of model derivation. From chosen models are in this category model of Ball and Plate, model of Hydraulics and model of Helicopter.

The analytical identification is usually based on physical laws. Application of this method is very exact, if structure and parameters of the real system are known. The results of the analytical identification are presented in [3], [4], [23]. Mathematical models of mechatronics systems can be implemented in the simulation software e.g. Matlab/Simulink.

Experimental identification using methods based on the Least Square method [19] or methods base on Neural Networks [5], [18]. For this methods are very important measured input and output signals from identified system. The experimental identification can be realized by System Identification and Neural Network toolboxes of Matlab/Simulink.

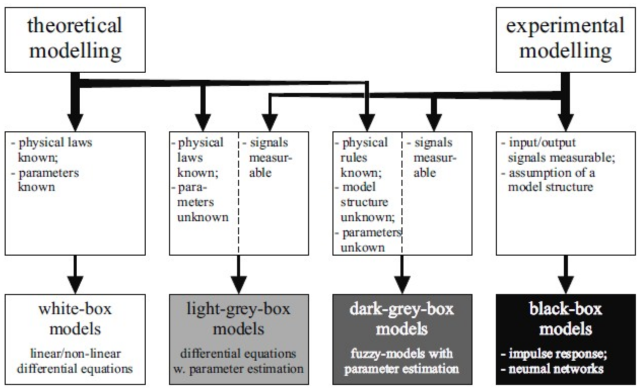

Fig. 2 Different kind of the nonlinear systems models [17]

The second category includes discrete-event systems and representative models are assembly lines [20]. Assembly lines can be modelling in continuous or discrete time form, too. Systems of this type are usually called Finite State Machines (FSM). For modelling of these systems are used state diagrams or tools like CPN Tools, Stateflow, SMI++ [6], etc.

Some processes with continuous manners can be transformed to the FSM model shape. In [7] is presented the Three Tank System in hybrid form. Continuous and discrete dynamics of the tanks are modeled separately. Continuous part is represented by the differential equations based on the law of the mass conservation in each tank. Discrete part is modeled by defining three binary variables and defining the logic statements associated with each binary variable. The three binary variables represent the three valves in the tank model with on/off states. The logic statements are defined depending on the valve positions.

IV. Control Design at the Control and Regulation Level of DCS

Control theory for systems with continues states includes many types of algorithms, but in PhD. thesis should be designed and verified mainly PID/PSD and LQ controller, adaptive controllers, predictive controllers and neural network controllers. Very important in the algorithm implementation is choice of the system sample period for correct computing and realization of the system control input.

The algorithms of the digital PID or LQ control was presented in many articles. These methods are very useful for simple implementation to PLC's or technological PC's control. Time of the control input computing is very quick and this reason is their main advantage.

The adaptive controllers are successful implemented to systems without knowledge about their mathematical model, what is their main benefit [8]. These algorithms can be implemented to PLC's or technological PC's, too.

Modern methods of processes control are algorithms based on prediction of the system state or neural networks. These algorithms are more complex than digital PID or LQ controllers, but there are many advantages of these algorithms. A predictive algorithm provides smoothness control input. Also, predictive algorithms are very useful for target of the reference trajectory tracking [23]. Neural networks provide independence from the linearization in the one equilibrium point, so they are more complex for the targets like a reference trajectory tracking, too.

Predictive control is based on prediction of the future system manners in the control structure. This prediction is derived from the model of the system. Predictive control algorithms can be divided in terms of many different manners, but mainly in terms of the used model of the dynamic system. Predictive control based on the ARX or CARIMA model form is Generalized Predictive Control (GPC) [9]. Also predictive control based on state space form is Model Predictive Control (MPC) [10]. Both algorithms used linear predictor [18], [21].

Another approach to dynamic system control using neural network. In [11] is used Feedforward Neural Network in control structure for computing of the nonlinear system control input. Another approach of using neural networks is in conjunction with predictive control algorithms. Neural network predicts future states of the system based on knowledge of current values of system inputs and outputs [12], [18].

FSM control consists of the specified conditions for transitions between states of the system. Control is usually realized by PLC's with algorithms in ladder logic form.

Design and implementation of these presented control algorithms will be a next part of my PhD. thesis. At first, the main aim will be their testing and verification on the simulation model. After successful results of the simulations, verified algorithms could be implemented and tested to the real laboratory models.

V. Diagnostics at the Technological, Control and SCADA/HMI with Simulation Models Level of DCS

Diagnostics is a recurrent thematic in research. Therefore is not surprising to find contributions from distinct areas: mathematics, system engineering, artificial intelligence, etc. As a general rule, different approaches can be classified as quantitative or qualitative depending on the nature of the measurements and/or observations being made over the system. In the industrial domain diagnosis is typically applied to an individual device or to the entire system [13].

The first three levels of DCS are suitable for implementation of diagnostics methods. Diagnostics algorithms are implemented like a part of the control structure with the real model which is in DCS represented by the Technological and Control level. This problematic contains many different methods and approaches. Very important for diagnostics methods are online input and output signals measurements. Similarly as in the previous section, very important is value of the sample period for online detection of the system faults. Type of the system and value of the sample period have influence to the choice of the diagnostics methods.

The SCADA/HMI level is usually used for visualization of low level processes and for their faults, too. Very important parts of this level are simulation models which describe low level processes by simulation software. Simulation models provide good opportunity for testing and validation of design control and diagnostics algorithms of dynamical systems.

In [17] is presented division of the fault diagnostics methods. From all of these methods is the aim of my PhD. thesis to choose right methods for selected laboratory models. Fig. 3 illustrated tree with fault detection diagnostic (FDD) methods.

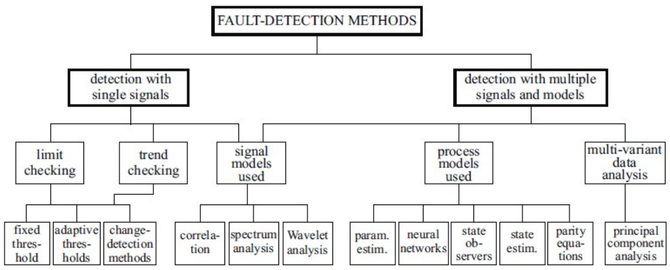

Fig. 3 Different kind of the nonlinear systems models [17]

For the chosen model in section II are useful methods based on the parameter estimation, state estimators or neural networks according to specified control algorithms in section III. These FDD methods are derived from the model of the system. Model of the system can be represented by transfer function, state space form or neural networks.

First of all for implementation of the FDD methods is tested and verified on simulation models. The evaluation of the simulation results decides about suitability of FDD method for implementation to chosen laboratory model or real process at the technological level.

At the technological level could be included systems with periodic manners like a motors or gearboxes. In [17] are systems with periodic manners called Signal models. Types of these systems are one of the possible topics in my PhD. thesis. For diagnostics of these systems are used algorithms based on the Fourier transformation, e.g. Fast Fourier Transformation (FFT) [17].

The FFT represents a periodic signal using a family of complex exponents with infinite time duration. Therefore, FFT is useful in identifying harmonic signals [14].

Another method for signal analysis is based on decomposing of the signal $x(t)$ into a family of functions which are translation and dilatation of a unique-valued function $\psi(t)$, to give the wavelet transform [15].

Signal Processing Toolbox of Matlab environment includes functions for Fourier transformation and Wavelet Toolbox is intended for wavelet transformations.

Last of the possible diagnostics systems are FSM models. For diagnostics of these types is possible to use Fault trees analysis (FTA). In operating safety and reliability science, the FTA is widely used tool to clear out the contributions of different parameters in an undesired event. A fault tree is defined as a graphical representation of the relationship between an undesired event (called a top event) and all its potential causes. The analysis proceeds in a "top–down" approach, starting with the top event (failure, ...) and determining all the causes that can lead to it. It determines how these top events can be caused by individual or combined lower level failures or events [16].

This method should be used for assembly lines diagnostics in my PhD. thesis. Another approach to using the FTA method is in application to hybrid systems. The answer to question if it is possible is one of aims of PhD. thesis.

VI. Conclusion

This paper provides a review of the methods of the modelling, control design and diagnostics applications. These methods may be used for implementation to the chosen simulation models from DCS, shown in Fig. 1. After their testing and verification these algorithms could be implemented to the real processes at the Technological level of the DCS. Main purpose of my PhD. thesis should be in choice of the modelling methods and in correct design of control and diagnostics algorithms. Another purpose should be in their correct combination and successful implementation in the simulation or technological level of DCS.

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