INTELLIGENT HIERARCHICAL CONTROL SYSTEM FOR COMPLEX PROCESSES

Three Levels Control System

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Abstract: The paper presents a concept of intelligent hierarchical control for complex dynamical processes and suggests architecture of control system consisting of robust, adaptive, and self-organizing levels. Intelligent features of the proposed system are mostly concentrated at self-organizing level incorporated into self-learning, self-configuring, self-optimizing, and decision making algorithms. State-of-the-art at each level is described. Case studies have been chosen from the area of plasma control in tokamak-reactors.

1 INTRODUCTION

Recent advances in control strategies, communications, hard and soft-computing technologies have favoured an increasing trend towards the new generation of networked control systems for complex processes. The proposal described herein will address the development of scalable control methods and systems in accordance with the Information and Communication Technologies (ICT) Work Programme, ICT-2009 3.5a: Foundations of complex systems engineering: To achieve robust, predictable and self-adaptive behavior for large-scale networked systems characterized by complex dynamic behavior through the development of novel abstractions and scalable methods for sensing, control and decision-making. The scope covers foundational multi-disciplinary research and proof of concept addressing the whole chain from modeling, sensing, monitoring and actuation, to adaptive and cooperative control and decision making (European Commission, 2008).

To meet the goal stated by the EC a three level intelligent hierarchical control system was suggested by Bauman Moscow State Technical University to be applied to solve control problems of complex dynamic processes in science, engineering, and industry.

The project is focused on design and development of scalar (Single-Input/Single-Output: SISO) and multivariable (Multi-Input/Multi-Output MIMO) networked control systems based on scalable control algorithms for uncertain time-varying nonlinear complex dynamic processes.

The major innovation of the proposal implies the elaboration of a new methodology for designing hierarchical adaptive self-organizing control systems to be applied to complex production processes, such as: plasma energy release, chemical and biological processes, casting in metallurgy, oil refinery, and so forth.

2 PHILOSOPHY OF HIERARCHICAL CONTROL

Industry and academia have investigated a wide range of decentralized control architectures ranging from hierarchical decomposition to a completely decentralized (heterarchical) approach where individual controllers are assigned to subsystems and may work independently or may share

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data/information.

The main disadvantage of heterarchical approaches is that global optima cannot be guaranteed and predictions of the system's behaviour can only be made at the aggregate level. Hierarchical and heterarchical architectures lie at opposite ends of the distributed control architectures spectrum. The hierarchical approach is rigid and suffers from many of the shortcomings of the centralized approach, whereas it provides clear advantages in terms of overall system coordination alternatively. The heterarchical approach is flexible and fault-tolerant, but arguably difficult to coordinate.

Hierarchical control and supervision schemes have been widely studied as a possible solution for optimizing complex systems. A variety of schemes can be implemented in order to profit from the advantages of this architecture, and the applications run all the way from fault-tolerant aircraft control problems to servo systems supervision (Kwong et al., 1995).

Hierarchical control allows any available data from the low-level control system to be used at a higher level to characterize the system's current behaviour. Moreover, hierarchical control can be used to integrate extra information (in addition to that concerning the usual control-loop variables such as output, error, etc.) into the control decision-making process. In many situations a hierarchical approach is an advantageous option for process optimization, instead of sophisticated design and implementation of high-performance low-level controllers, because the hierarchical approach can compensate factors that are not taken into account in the design of low-level controllers (Berenji et al., 1991).

Thanks to its own structural essence, the hierarchical control scheme ensures flexibility and compatibility with other controllers that have already been installed. It has other strong points as well, such as the relatively low cost of investments in improving automation scheme performance, the possibility of exploiting already-installed low-level regulation systems, and the relatively low cost of measurement systems which makes hierarchical control a wise choice from economic and practical viewpoints.

The hierarchical methodology will cover three basic levels, namely:

I) physical control level composed of controlled process interacting with robust or classical controller through sensors and actuators;

II) adaptive level that implements scalable adaptation algorithms and enables the robust controller to satisfy a number of time-varying constraints;

III) knowledge-based self-organizing level which executes a set of self-learning, self-configuring, self-optimizing, and decision-making algorithms allowing possible dynamic changes in the system architecture aimed at optimal control and dynamic reconfiguration of the robust controller and making it easier to satisfy process-critical constraints, such as respond to the deadlines, saturations and so on.

Advanced algorithms designed for all control levels I, II, III and their interactions provide a *high degree of system flexibility, robustness, accuracy, reliability, dependability, and survivability* to deal with disruptive, uncertain, and unforeseen events *in automatic mode* (without human intervention).

The philosophy of the three-levels intelligent hierarchic control system proposed is a strategy of the project to be organized. Complex processes under control should be first of all thoroughly investigated, then classical or robust control systems are to be developed. After that, improvement of lower level should be done by means of levels II and III including decision making approach which may be performed by experts at the beginning of system design and not in automatic mode.

3 STATE-OF-THE-ART

The design of the main SISO and MIMO control loops should be based on, in a certain sense, classical approaches which have been used in modeling and practice and demonstrated efficacy in a number of applications. These approaches are based on design principles for which reliable dynamic processes models are created by means of First Principle Equations methodology (Khayrutdinov et al., 1993, Leonov et al., 2005), identification (Mitrishkin, 2004), linearization and subsequent reduction procedure. The resulting real world models have been used in system closed-loop to predict optimal control actions at each discrete timing interval to achieve the control goal taking into account input constraints (Mitrishkin and Korostelev, 2008). Decoupling control leads to the design of astatic multivariable systems (Leonov et al., 2005). A number of optimization approaches, specifically off-line Linear Quadratic techniques (Belyakov et al., 1999), H_∞ and μ synthesis

(Mitrishkin et al., 2003, Ariola and Pironti, 2008) as well as online automatic optimization of extremum search (Mitrishkin, 2004), gave acceptable results. Adaptive Kalman filter made it possible to estimate process parameters in real time and gave a chance to adapt the system by adaptive algorithm to time-varying process parameters (Mitrishkin and Kuznetsov, 1993). As this took place, an external disturbance was estimated and estimation value was used to compensate the disturbance itself (Mitrishkin, 2004).

Some results in the topics in relation to this proposal are the design and implementation of: intelligent hierarchical control and supervisory systems (Peres et al., 1999); control strategies by fuzzy, neural, neuro-fuzzy, and evolutionary neuro-fuzzy internal model control systems (Haber et al., 2004); rapid control prototyping for networked and embedded control (Haber et al., 2008); embedded intelligent control systems in open architectures (Haber and Alique, 2007), and networked control and intelligent monitoring for macro- and micro-scale manufacturing processes (Haber et al., 2008).

The synthesis of intelligent hierarchical control system (Andrikov and Konykov, 2004) was applied to improve car braking controllability by H_∞ control theory.

4 STATEMENTS OF CONTROL PROBLEMS

A number of new important complex control problems have to be studied, discussed and formulated to achieve control goals of acceptable trade-off between robust stability and performance of feedback systems. The problem statements concern the stabilization and tracking process output signals, optimal distribution of process parameters in space in the presence of non-modeled process dynamics, unobserved disturbances, nonlinearities, in particular saturations, wideband insufficiently known noise in output signals, non-minimum-phase dynamics, and time-varying parameters. To solve these control problems a set of approaches from linear and nonlinear control theory will be explored and developed to achieve scalable H_∞ robust, decoupling, model predictive, adaptive, hierarchy, cascade, soft-computing based control (e.g., neuro-fuzzy control systems), and facilitate decision-making in new appropriate combinations within continuous and discrete time of the three-level hierarchic control system. Scalable control algorithms mean that the algorithms may be generalized to any numbers of controlled plant inputs, outputs, and space states.

5 PRACTICAL APPLICATIONS

In order to validate the suggested approaches plasma energy release case study is planned to be investigated. Control methodologies will be applied to plasma vertically unstable position, shape, and current in the presence of voltages and *current saturations* in poloidal magnetic coils in ITER (International Thermonuclear Experimental Reactor, www.iter.org). Multivariable robust controller design (level I) *with adaptation* on the level II is proposed to be done for the *whole plasma discharge* of plasma current ramp-up, ramp-down, and at quasi stationary stages. It is planned to be applied for ITER reference scenario No 2 with plasma current on flat-top of 15 MA and for reversed share scenario No 4 of plasma current of 9 MA. Mathematical modeling of control systems to be developed on plasma-physics code DINA (Khayrutdinov et al., 1993) is assumed to be fulfilled in tracking and stabilizing modes at disturbances of minor disruption type.

The project control methodologies are planned to be applied to solve *plasma kinetic control problem* as well. Plasma kinetic control means creation and maintenance of *optimal* plasma current, temperature, and density profiles by means of additional heating sources. Such regimes are necessary for stationary operation of tokamak-reactors. Development of kinetic plasma models of plasma current, temperature, and density profiles and their identification are supposed to be created. Then design and modeling of plasma profiles control systems are assumed to be performed.

The final issue of this activity is integration of plasma magnetic and kinetic control systems.

In the process of hierarchical structure control systems design the synthesis, analysis, and numerical modeling approaches are proposed to be performed in MATLAB/SIMULINK environment.

The ITER functionality is planned to be performed by means of CODAC software specifically Control, Data Access, and Communications (www.iter.org) via which one can install hierarchical control scheme proposed.

6 CONCLUSIONS

The concept of three levels hierarchic control system was presented and discussed namely: architectural details, state-of-the-art, statement of control problems, and practical applications.

The project will result in the creation of new process models, procedures of their identification and reduction, efficient, robust, predictable, and safe ICT control methodologies, scalable control algorithms, and high-performance controllers with reconfigurable architecture for the problem oriented hierarchical systems under consideration. Scientific, engineering, and industrial results will be accumulated in the data and knowledge bases with accurate classification, qualitative and quantitative assessment, and generalization.

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