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Multi-agent controller using soft computational paradigms

KEYWORDS: Multi-agent controller, Soft computational paradigms, Multi-agent control architecture, Water tank system

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ABSTRACT *This paper presents an innovative nonlinear multi-agent controller using soft computational paradigms. This control, includes different control algorithms, is useful for nonlinear processes whose properties having different operating regimes. It is designed using the concepts of agent based systems, applied with the aim of automating some of the configuration tasks. The different process model with operating regime is derived using online system identification procedure. The multi-agent based controller is evaluated the best control algorithm using control performance parameters and implemented on process. The performance is illustrated on the nonlinear water tank system and results are discussed.*

1. Introduction

Modern control theory covers many control techniques to achieve more efficient control of nonlinear processes than provided by conventional linear methods, taking advantage of more accurate process models (Henson & Seborg, 1994; Murray-Smith & Johansen, 1997). Surveys (Bauer & Craig, 2008) indicate that the demand of advance controller is very high and growing high continuously.

Excellent results of various control techniques are reported as multiple model control, intelligent control, adaptive control and agent based control (Breemen & Vries, 2001; Garcia, Cardenas, Puglisi, & Saltaren, 2012). There is some delimitation of the methods according to industrial demand as summarized as below.

- Lack of ready to use methods for industry environment. Custom design requires considerable effort, time and money.
- Diversity of real-life problems needs multiple algorithms.
- Complex hardware leads to difficulties in maintenance at factory site.
- Reliability of nonlinear modeling is often question.
- Replacement of the existing system is costly

Paper describes design of an advanced controller that addresses some of the problems by using the concepts of multi-agent systems (MAS) (Wooldridge & Jenning, 1995) by partial automation of the commissioning procedure to simplify controller configuration. MAS employ software agents which are characterized by properties such as autonomy, social ability, reactivity, pro-activeness etc.

Multi-agent controller is designed using new framework based on the concept of an agent, which has been introduced from the field of artificial intelligence (Wooldridge & Jenning, 1995) and has found its way into the field of control engineering (Breemen A. , 2001; Vatankhah, Etemadi, & Alasty, 2012). A new agent is proposedwhich is the basic building block of the presented framework. It provides an open environment in which the addition, removal or change of an agent can be performed without the need to redesign the entire control system. The agents are designed using different soft computing techniques to reduce the high computational demands.

Designing a controller for nonlinear water tank system is describedto emphasize the effectiveness of Multi Agent Control (MAC) frame.The design problem is solved by properly structuring (decomposing) it into a set of subproblems. Each sub-problem is solved by designing a particular agent. The overall solution is obtained by combining all agents into one system using coordination object.

The outline of the paper is as follows: Section-2 presents an overview of the multi-agent control architecture and describes its most important modules; Section-3 gives a brief description of the water tank system; and finally, Section-4 describes the application of the MAC controller to the plant and its results analysis.

2. Multi-Agent Control Architecture

This is new approach of control scheme on the base of multi-agent system (MAS). This can be used for non-linear SISO or MIMO applications. The whole control problem is structured in partial control problems. The agent is design to solve the partial control problem. The specific goal is assigned to it and it is activated on respective active region to achieve it. This is a layered structure of MAS in which different layers have different objective. The overall distribution is in four sections: Identification, Performance Analysis, Control algorithm, Coordination. Fig: 1 shows the architecture of multi-agent and its components: Signal pre-processing agent (SPA), Online learning agent (OLA), Model information agent (MIA), Performance measure agent (PMA), Citric agent (CA), Control algorithm agent (CAA) and Coordination object (CO).

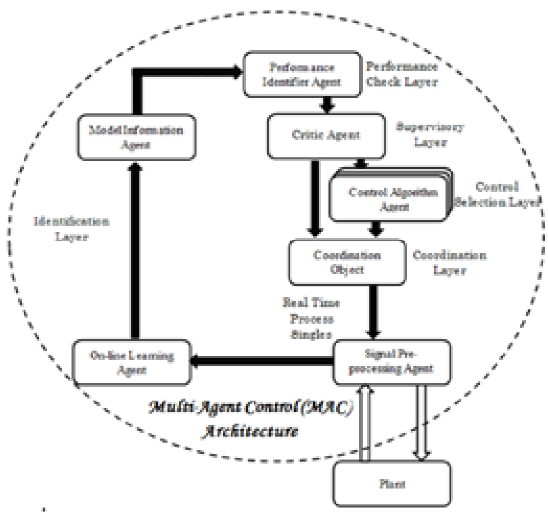

Figure: 1 Multi-Agent Control (MAC) architecture

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2.1 Identification

The local model is identified using nonlinear autoregressive network with exogenous inputs (NARX) approach base on present condition of system. It is a recurrent dynamic network, with feedback connections enclosing several layers of the network. The NARX model is based on the linear ARX model, which is commonly used in time-series modeling (Baldacchino, Anderson, & Kadirkamanathan, 2012; Ljung, 1999). Figure: 2 is the flow chart of identification and it is distributed in two sections.

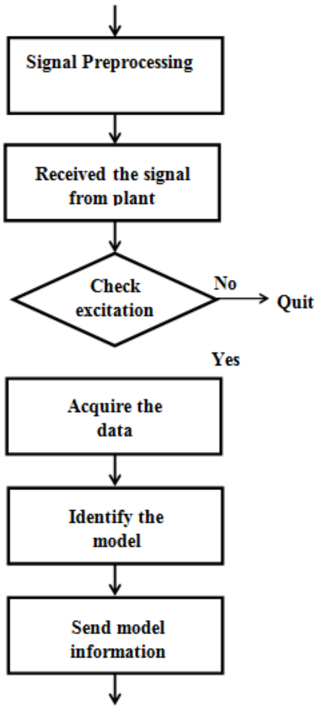

Figure: 2 Online identification

2.1.1 Online learning agent (OLA)

The OLA scans the buffer of recent real-time signals, prepared by the signal processing agent (SPA), and estimates the parameters of the local models that are excited by the signals. The most recently derived parameters are submitted to the MIA only when they pass the verification test and are proved to be better than the existing set.

2.1.2 Model information agent (MIA)

Its primary activity is processing the online learning results. When a new local model is received from the OLA, it is accepted if it passes the stability test and its confidence index is sufficient. If the model confidence index is very low, the automatic mode may be disabled. At initial configuration, the MIA is filled with default local models based on the initial estimation of the process dynamics. They are not exact but may provide reliable (although sluggish) control performance, similar conditions are appropriate for closed-loop identification), an accurate model of the plant is estimated gradually by receiving identified local models from the OLA.

2.2 Control performance assessment (CPA)

The control performance assessment (CPA) scans the buffer of recent real-time signals for recognizable events. When events are detected, it estimates the features of closed-loop control response and an overall performance index (Liu, Huang, & wang, 2011; Patel & Shah, 2011). This is performed by PMA. After CA will be activated the respective control algorithm agent and also identified coordination object design.

2.2.1 Performance measure agent (PMA)

It checks if the process is in a steady-state; if so, it terminates processing. If an event that may be evaluated is detected and the conditions for feature estimation are fulfilled so the performance estimator is excited. It may extract the following features of detected events: overshoot, steady state error, variance in output, rise time, settling time, reference change. The figure: 3 is given flow chart of working. The consulate array of performance measure is passed to critic for further analysis.

2.2.2 Critic agent (CA)

The parameters of performance are copied from buffer of PMA. It is difficult to identify the suitable control algorithm directly for particular operating regime of available data. The critic agent (CA) is designed using fuzzy logic to generate the activation signal for coordination object (Addullah, Hussain, Warwick, & Zayed, 2008; Hespanha, Liberzon, Morse, Anderson, Brinsmead, & Bruyne, 2001). The various inputs membership functions, rule base and output membership functions are assigned with help of whole operating performance of this parameter.

The member functions are designed from experimental study for various parameters as given in table: I. The rule base is selected so it will cover with minimum rules with all operating conditions of plant. The rule base is given in table: II.

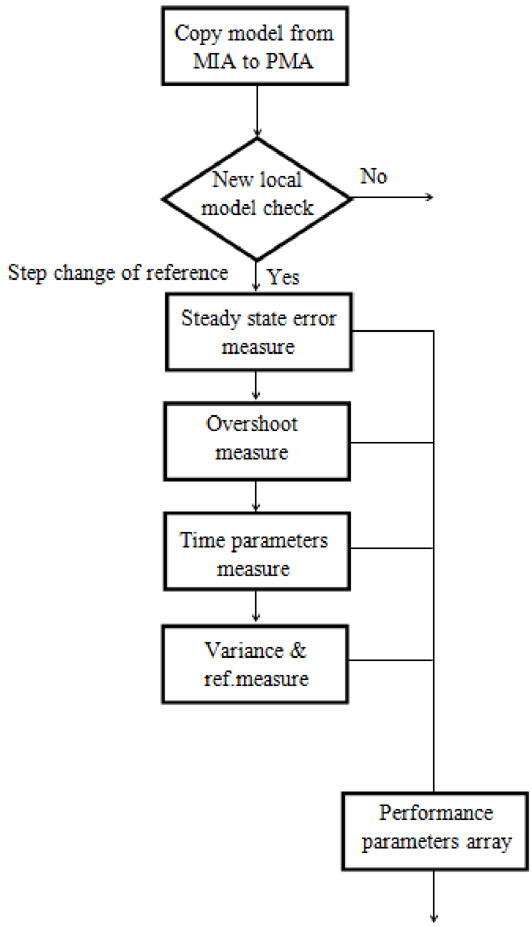

Figure: 3 Control performance assessment

2.3 Control Algorithm Agent

The CAA comprises an industrial nonlinear control algorithm with automatic tuning of its parameters. Several different CAAs may be used in the controller and may be interchanged in the initial configuration phase. The following modes of operation are supported:

Table I: Membership function for various parameters

Parameter	Actual Range	Range (%)	Name of Mf	Type of membership function	Mf range
Overshoot	0 to 500	0 to 100	Low High	Triangle Trapezoidal	[-5 0 100] [0 20 20 100]
Steady state error	-5 to 5	-100 to 100	N-error M-error P-error	Trapezoidal Triangle Trapezoidal	[-100 -100 25 16] [-21 0 21] [16 25 100 100]
Variance in output	0 to 40	0 to 100	Low High	Trapezoidal Trapezoidal	[0 0 5 100] [0 10 100 100]
Rise time	0.1 to 500	0 to 100	Fast Average Slow	Triangle Trapezoidal Trapezoidal	[0 0 10] [5 10 20 25] [20 40 100 100]
Settling time	20 to 500	0 to 100	Fast Optimal Slow	Trapezoidal Triangle Trapezoidal	[0 0 20 30] [20 40 60] [50 60 100 100]
Reference change	-15 to 15	-100 to 100	Dec Norm Inc	Trapezoidal Triangle Trapezoidal	[-100 -1000 -5 0] [-5 0 5] [0 5 100 100]

Manual mode: open-loop operation (actuator constraints are enforced)

Classical Mode: a fixed PID controller with conservatively tuned parameters

Intelligent mode: a nonlinear controller or several modes with different intelligent methods for different operating regime

Three CAAs PI, Fuzzy and NN have been developed and each has been proved effective in specific applications. More controllers can be included for better performance.

2.4 Coordination object

Choosing the coordination object given the interdependency mechanism between different CAAs is of major importance as coordination object may have considerable impact upon the performance of controller (Breemen A. , 2001). Two types of design are normally used based on dependency.

Table: II rule base for critic agent

Rule base	
Overshoot is High and steady state error is N-error	NN
Overshoot is High and steady state error is M-error	PID
Overshoot is High and steady state error is P-error	Fuzzy
Rise time is fast and settling time is fast	NN
Rise time is fast and settling time is slow	PID
Rise time is slow and settling time is fast	NN
Rise time is slow and settling time is slow	PID
Variance is low	PID
Variance is high	NN
Reference change is norm	PID
Reference change is Inc or Dec	NN

2.4.1 Competitive: This coordination mechanism is used in situations in which a hard decision has to be made between CAAs. This means that given a set of CAAs that wants to get active simultaneously, there is only one CAA that will get a positive acknowledge.

2.4.2 Cooperative: This coordination mechanism is used in situations where soft decisions must be made between CAAs. This means that control actions of different CAAs have to be blended somehow.

In this design, the MAC architecture is designed using competitive coordination object.

3. Field application

Industrial applications of liquid level control abound, e.g., in food processing, beverage, dairy, filtration, effluent treatment, and nuclear power generation plants, pharmaceutical industries; water purification systems; industrial chemical processing and spray coating; boilers; and automatic liquid dispensing and replenishment devices. So, highly variant system of water level control is selected as field study for primary application of multi-agent controller (Johansson, 2000). The following symbols should be given first:

F1 = Inlet flow through pump

F2 = Outlet flow of discharge

H = Height of tank water level

A = Cross-sectional area of the tank

K = Constant related to the flow rate

V = Input voltage of pump drive

α = Flux proportional coefficient

Here only the dynamic character of tank is analyzed. Consider that A, K and α are time invariant parameters. Vo, and Ho are the input and output value of an equilibrium point, then the dynamic of system is:

$$F_1 - F_2 = A\frac{dH}{dt}$$
$$F_1 = KV$$
$$F_2 = \alpha\sqrt{H}$$

Performance of MAC control algorithm on above process has been analyzed.

4. Controller performance

Multi-agent controller is applied on the water tank control system. The overall performance is checked with classical control system.The classical control with nonlinear with noise plant is given in this figure 4. The required control effort response is also given in figure 5. This is tracked the set-point but continuous variation observed. If the system is having continuous changing in operating condition and its plant operating parameters so the classical control is not suitable with good efficiency. New plant operating parameters are observed during the operation, the OLA is identified the current plant model. The PMA is verified the plant model information.The performance of plant is given by PMA. The critic agent activates optimized and efficient CA for particular environment using different close loop parameters of plant. The table: III is given the result of CA for different parameters. Finally, the agent is applied on plant using competitive coordination. The controller is continuous checking the plant performance and best algorithm is applied on the plant during respective operating regime. The result of this controller with various operating regime with noise are given in figure 6 & 7. This structure is flexible so that the more control algorithm can be included as per plant performance and its operating regime. If the plant is nonlinear with noise, MAC concept is efficient compare than classical control.

Table: III Parameters value and control algorithm agent

Overshoot (%)	Steady state error (%)	Variance in output (%)	Rise time (%)	Settling time (%)	Reference change (%)	CAA Activation
96.1	15.7	97.8	40.0	55.8	-20.9	NN
17.0	73.0	2.17	22.2	50.0	-22.6	Fuzzy
66.5	29.6	30.9	23.9	44.5	53.9	PID
27.4	-48.7	34.3	43.8	53.8	26.1	NN
82.2	-10.4	3.91	9.13	13.9	73.0	Fuzzy
27.4	69.6	66.5	24.8	50.8	-3.48	PID

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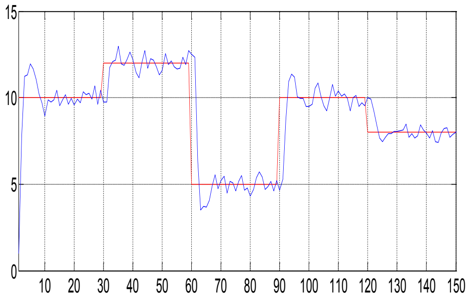

Fig: 4 Classical control performances on control problem

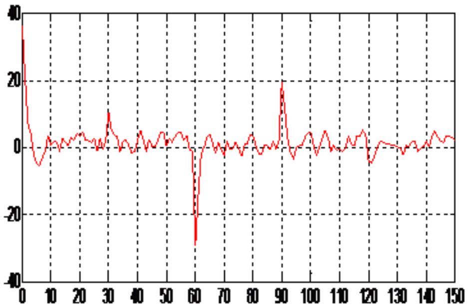

Fig: 5 Control effort required through classical control

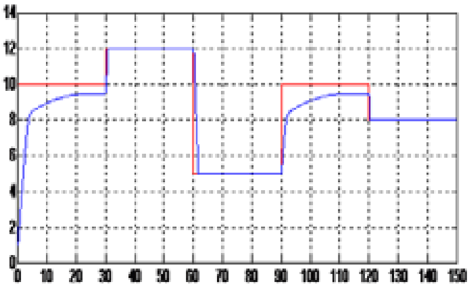

Fig: 6 Multi-agent control performances on control problem with various set points

Conclusion

A new multi-agent controller has been successfully designed. Most agents are implemented using soft computational paradigm to optimize its design. Several pilot applications, including the one presented in this paper, have also been successfully completed. Compared to the industry standard PI controller, an expected considerable improvement in the control performance was achieved using the MAC control algorithm. The modular multi-agent structure contributes to remarkable flexibility of the control system, so that it is easily reconfigured for various requirements. The work is currently directed towards further improvements in the simplicity of use and ease of application to new more nonlinear processes. A promising future research direction is coordination object design for hard condition dependency approach which may result in a positive contribution to the reliability of adaptive control. The online performance evaluation is required some time. More research is required in this area to generate more efficient control.

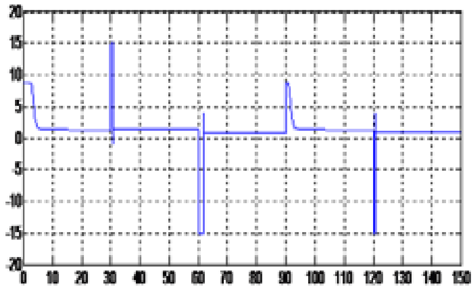

Fig: 7 Control effort required through multi-agent controlwith various set points

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