REAL-TIME INTELLIGENT DISTRIBUTED CONTROL SYSTEMS

by

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CERTIFICATE

This is to certify that the thesis entitled, "REAL-TIME INTELLIGENT DISTRIBUTED CONTROL SYSTEMS" being submitted by **Nesar Ahmad** for the award of the degree of DOCTOR OF PHILOSOPHY to the Indian Institute of Technology, Delhi is a record of the bonafide research work he has carried out under our supervision. The results contained in this thesis have not been submitted to any other University or Institute for the award of a degree or diploma.

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ABSTRACT

The thesis investigates knowledge representation and reasoning approaches based on qualitative and fuzzy set theory for modeling, analysis and design of intelligent controllers for real-time implementation for servo and regulatory control of levels in a coupled two tank system. The thesis presents *Artificial Intelligence* (AI) based modeling methodologies and design of a set of intelligent process control algorithms, based on the theory of fuzzy sets, and their real-time implementation in a distributed control environment on a laboratory scale pilot plant. These intelligent controllers include Fuzzy Linguistic/Logic Controllers (FLC), Self-Organizing Fuzzy Logic Controllers (SOFLC) and Heterogeneous Fuzzy Logic Controllers (HFLC).

The thesis describes the development of a test bed for testing the efficacy of intelligent distributed control algorithms. A design and implementation of a real-time data driven communication protocol for building a Small Area Network in star topology is described. The thesis also investigates the feasibility of using off-the-shelf Local Area Network (LAN) based on CSMA/CD protocol for low level control applications.

In order to perform the implementations of such controllers, the thesis develops a real-time system [Stankovic,88] setup (test bed) that consists of a laboratory scale pilot plant (controlled system) and a computer communication networks (controlling system) interfaced to the pilot plant. This setup is referred to as an Intelligent Distributed Control Setup (**IDCS**). Two types of communication networks have been developed namely; a star network by designing and implementing a real-time communication protocol, and a real-time bus network by designing and implementing an application layer software on top of off-the-shelf CSMA/CD network through fully shared files on RAM drives [Ahmad,90][Ahmad,91].

The knowledge based framework allows to incorporate heuristics, common-sense knowledge, natural language statements and causality as well as experience, along with various kinds of numerical algorithms. The fuzzy algorithm mainly consists of a set of linguistic control rules which can be represented and implemented on

a process control computer using heuristics, fuzzy sets and compositional rule of inference [Zadeh,73]. The main design problem of FLC algorithm lies in the formulation of a finite set of linguistic control rules for a particular situation, as there is no rigorous synthesis procedure for developing such rules. The linguistic rules are generally developed based on the operator experience but there may be situations where no such experience is available. Another method to derive rules is based on desired response of the process by applying control engineering expertise [Sugeno,85a]. This thesis proposes an alternative method to derive rules which is based on qualitative abstraction of the conventional PI(D) controller structure [Ahmad,92a]. The tuning of FLC is done based on analogy between the scale factors in FLC and controller parameters in conventional PI(D) algorithm. Distributed FLC responses for 3 and 7 fuzzy subsets over the input and output universes of discourse of the pilot plant variables are compared with PI response.

The other approach to generate rule is due to Procyk and Mamdani, which develops its own rules on-line that will satisfy a predefined acceptable controller response (closed-loop performance). This fuzzy controller can be started with no rules at all and will quite quickly have an adequate and consistent rule set, which is modified during several test runs of controller response. An improved SOFLC algorithm has also been proposed by Sugiyama to get rid of the slow response and unacceptable steady state errors in SOC algorithms. The thesis develops a computationally simpler version of Self-Organizing Controller for real-time implementation. The simplicity is achieved by imposition of some constraints on the definition of fuzzy subsets (convex, normal, symmetric and sometimes unimodal). The fuzzy subsets are defined over continuous universes of discourse, but they are defined around discrete and finite number of support elements in the universes of discourse of measurements and control output. The simplification in algorithmic computation in rule modification procedure (learning mechanism) is achieved by defining fuzzy subsets for all support element over the universes of discourse. A modified center of area (COA) method has been used as defuzzification strategy. The real-time results are presented to demonstrate SOFLC's ability to operate over a wide range of process variables (non-linearity) and time varying dynamics.

In order to alleviate the problem of steady-state error in FLC and SOFLC, the thesis presents a design and tuning of a Heterogeneous Fuzzy Logic Controller (HFLC) consisting of a simple FLC and a set of PI controllers. The controller reaps the benefit of both the conventional as well as fuzzy controller by combining the two algorithms using qualitative/fuzzy framework.

The thesis also presents the development of software for real-time implementation of the Intelligent Controllers on distributed computing nodes. Most of the software for the IDCS has been developed in Microsoft 'C' language under MSDOS environment.

To my parents

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