Chapter 18
Numerical Simulation of Distributed Dynamic Systems using Hybrid Tools of Intelligent Computing

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ABSTRACT

Developing fast and accurate numerical simulation models for predicting, controlling, designing, and optimizing the behavior of distributed dynamic systems is of interest to many researchers in various fields of science and engineering. These systems are described by a set of differential equations with homogenous or mixed boundary constraints. Examples of such systems are found, for example, in many networked industrial systems. The purpose of the present work is to review techniques of hybrid soft computing along with generalized scaling analysis for the solution of a set of differential equations characterizing distributed dynamic systems. The authors also review reduction techniques. This paves the way to control synthesis of real-time robust realizable controllers.

INTRODUCTION

A large number of processes in electrical, chemical, and petroleum industries are distributed in nature. Tubular reactors, electrical furnaces, are typical examples of distributed dynamic systems. The proliferation of mobile actuators and sensor networks (Estrin, 2001; Akyilidz, 2002) has contributed to the development of more distributed dynamic systems. Because of the diversity of distributed patterns, distributed dynamic systems can be highly nonlinear and time varying, and thus their modeling can be quite challenging. Thus, a significant number of modeling, control, and optimization applications arise for distributed dynamic systems. The mathematical description

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of distributed dynamic systems may be in the form of partial differential equations, integral equations, integro-differential equations.

The simulation of distributed dynamic systems is an essential part in the control design and optimization of many physical processes. Most used simulation tools are typically based on discretization oriented numerical techniques. These techniques provide accurate results but are highly CPU intensive, and thus are not feasible for online optimization and control studies. This solution time makes it inconvenient to generate and manage in a timely manner required engineering decisions. The unavailability of methods appropriate for online optimization of complex systems prompted the use of look up tables and curve fitting based on data obtained by off-line extensive simulations. Curve fitting can only handle mild nonlinearity variations and few variables at one time. Look-up tables are powerful since they require only a query on the table, and this is fast. However, they are bulky, costly, and memory intensive and are not easy to maintain and upgrade. Interpolation of a point in look up tables does not make use of the entire input-output data since only values in the neighborhood of the point are used. In addition, asymptotic and approximations techniques have often underlying assumptions, and therefore their accuracy is compromised.

The use of hybrid intelligent soft computing tools is an efficient method to create system solutions which are capable of learning relationships and then use this knowledge for further computations. Fuzzy logic is a research area that received considerable attention, and has been successfully used in system control and identification, as well as many other areas. A fuzzy system is developed in this chapter for the scaling of the mesh-based solution from another dynamic distributed system to another.

The objectives of the present work is to investigate the use of hybrid soft computing techniques along with generalized scaling analysis for the simulation of distributed dynamic systems in an interactive CAD and optimization providing faster on-line solutions and speeding up design guidelines, and then to develop reduced order models with the aim of formulating control solutions. The remainder of the paper is organized as follows. First an overview of generalized similarity analysis is presented. This is followed by specific details of the implemented fuzzy neural network. Demonstration of the proposed approach is illustrated on two distributed dynamic systems. The first involves the modeling of oil reservoirs. Reduced order models are then presented based on the neural network linear and nonlinear principal component analysis. The last section covers briefly control synthesis of low order distributed dynamic systems.

BACKGROUND

An input-output process model is a set of equations to predict the future outputs of a system based on input data. The model should closely represent the relationships between inputs, outputs, and system variables to reduce the error caused by plant-model mismatch. Distributed dynamic systems are often represented by partial differential equations. For example, a large number of processes in different industries are distributed in nature, thus a significant number of modeling, control, and optimization applications arise for these types of systems. The state variables depend on at least two independent variables (i.e. time and space). For example, a tubular reactor may be modeled by a second order partial differential equation describing the change in axial position in the reactor and in time. Partial differential equations can be discretized so the system is represented by ordinary differential equations at separate discrete spatial points, which can then be used to synthesize a model-based control.

Because of the diversity of distributed patterns, distributed dynamic systems can be highly nonlinear and time varying, and thus their modeling