Chapter 24

Swarm Bee Colony Optimization for Heat Exchanger Distributed Dynamics Approximation With Application to Leak Detection

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ABSTRACT

The process of heat exchange in thermal systems is generally characterized by complex phenomena that involve many uncertain, varying and distributed parameters. Reliable physical modeling of heat exchangers is rather difficult to achieve because of the complex dynamics. Approximations through lumping are usually considered for simplified modeling. However, simplifying assumptions might impact the model performance. Relying on lumped-parameter models limitations, this chapter presents an alternative swarm based fuzzy modeling methodology to design reliable temperature prediction models for heat exchanger process. Fuzzy rule-based models are self-generated from process measurements to predict temperature variations in the heat exchanger using a nonlinear modeling strategy based on artificial bee colony optimization. Experimental data collected from a parallel heat exchanger is used to test the designed temperature prediction models. An application study on water leak detection is also presented in order to assess the feasibility of the swarm fuzzy modeling methodology.

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INTRODUCTION

Thermal heat exchanger systems are important parts of many industrial processes. They are widely used in oil and gas, power, transportation, air-conditioning and refrigeration, heat recovery, and manufacturing industries. They can also be found as integrated components in various commercialized products in the marketplace. Their importance has significantly increased with regard to energy conversion and successful implementation of new energy resources. This satisfactory industrial integration level is in fact the result of advances in the development of heat exchanger manufacturing technology as well as design theory. Basically, a heat exchanger ensures heat transfer from one fluid to another through specific network configurations. Typical applications involve heating or cooling of a fluid stream. In other applications, the task may be to recover or reject heat, distill, concentrate or control a process fluid. The entire thermal design procedure of heat exchanger devices is based on only two fundamental relationships which are the enthalpy rate equations and the heat transfer rate equations (Shah & Sekulic, 2003).

From modeling viewpoint, fundamental or equivalently first principle laws lead to distributed-parameter model structures that may involve uncertain, nonlinear as well as varying parameters. For the sake of interpretability, the use of first-principle based models is usually preferred. However, it is rather difficult to design physical models with high reliability because of the complex physical phenomena in thermal processes (Shah & Sekulic, 2003; Thomas, 1999). With regard to dynamics complexity, models built upon partial differential equations (PDEs) are used to capture key dynamical properties of heat exchanger systems. PDEs based models are obtained from mass and energy balances, but remain of little interest for engineering applications. Simplified model structures can be derived from PDE models by using a lumping procedure (Thomas, 1999; Zavala-Rio & Santiesteban-Cos, 2007). Lumped-parameter models are obtained by dividing the whole exchanger in a finite number of cells in order to get a set of ordinary differential equations (ODEs). However, it is worth noting that lumping gives rise to high-order models when accurate modeling is required.

In this chapter, data-driven modeling is addressed to design suitable model representation for a heat exchanger process. The aim is to extract data-based models directly from the available measurement data to predict temperature variations of the fluids flowing through the exchanger pipes. For this purpose, a swarm optimization based modeling methodology is investigated to construct convenient self-generated fuzzy rule-based prediction models of inlet and outlet temperature variables. Experimental measurements collected from a pilot thermal plant are employed by using a self-generation fuzzy rule methodology developed in (Habbi, Boudouaoui, Karaboga & Ozturk, 2015). More precisely, the swarm based fuzzy modeling approach relies on artificial bee colony (ABC) optimization. The ABC strategy is one of the most popular swarm algorithms which has been introduced by Karaboga in (Karaboga, 2005) and applied successfully to various optimization problems (Karaboga, Gorkemli, Ozturk & Karaboga, 2014; Karaboga & Kaya, 2016; Karaboga & Basturk, 2007). The design method ensures simultaneous determination of the temperature fuzzy prediction models that are managed to evolve together through an optimization process based on honey bees foraging concept. An application study on water leak detection involving the obtained fuzzy rule-based models will also be investigated.

The chapter is organized as follows. After an introductory section, a literature review on the studied subject is given. Then, the problem context is detailed and motivations are provided. It follows a brief review of artificial bee colony optimization strategy. The subsequent section presents the ABC-based fuzzy rules generation strategy and describes its application to temperature variations prediction in a parallel heat exchanger process. Experiments and modeling results are then shown and discussed. To