

397d Ant-Colony-System-Based Dynamic Optimization

Jie Xiao and Yinlun Huang

Dynamic optimization is always a challenge methodologically and computationally, especially when a system to be optimized is highly nonlinear and complex. In this paper, we propose a novel dynamic optimization methodology based on the Ant Colony System (ACS) – a successful Ant Colony Optimization (ACO) algorithm. This population-based methodology was first introduced by Marco Dorigo et al. to tackle traveling salesman problems. It uses exploitation of positive feedback as well as greedy search in solution identification. Due to the charm of ant colony metaphor and the excitement coming from convincing applications, the ACO attracts increasing attention and becomes one of the standard meta heuristics for solving combinatorial optimization problems. However, a successful use of the methodology remains a great challenge.

In this work, a general mathematical framework is introduced as an extension of the original ACS for solving complex process dynamic optimization problems. In this framework, a solution identification process is expressed by a set of search trees and all the ants will work on this set of trees cooperatively. Each tree contains a number of nodes that are distributed in layers and a number of edges each of which connects two nodes in two adjacent layers. Each tree corresponds to a decision variable, which will be optimized jointly by a set of ants. The solution search utilizes three classical rules, i.e., the state transition rule, the local pheromone updating rule, and the global pheromone updating rule. In addition, a novel sequence determination rule is introduced to improve performance of ACS in dynamic optimization problems.

To validate the efficacy of this methodology, an automotive clearcoat curing process is studied thoroughly. Due to the complexity of physical and chemical phenomena occurred in operation and the lack of on-line measurement of key process and product parameters, coating curing ovens are always operated far from optimal in terms of coating quality and energy consumption. In this study, two cases are investigated: one for quality constrained energy minimization, and the other for optimal coating quality. In the first case, complex system dynamics (temperature changes, extent of conversion, coating film thickness and solvent removal dynamics) are modeled and the resulting problem is a large-scale multi-stage dynamic optimization problem with a mixed set of sparse linear and nonlinear time-dependent constraints. The objective function is time-dependent and it is a sum of interdependent sub-objective functions. Within a reasonable amount of time (20 minutes), the proposed methodology can generate a satisfactory solution (with 10% energy savings). The second case took advantage of a widely adopted cure window approach as the clearcoat quality evaluation criterion. It is demonstrated that the optimized settings can result in uniformed cure much closer to the optimal cure condition.

Above all, the principal contribution of this paper is to introduce a non-conventional ACS-based dynamic optimization methodology to chemical engineering realm. This methodology significantly extends the original version of ACS from solving steady-state optimization problems to tackling dynamic optimization problems. As to the application, it advanced successfully current post-process inspection-based reactive quality control in reactive drying of clearcoat to quality-prediction-based proactive quality control. This optimization methodology is, in general, applicable to a variety of industrial dynamic optimization problems, where product and process performance can be simultaneously considered.