Adaptive Simulated Annealing for Designing Finite-Precision PID Controller Structures

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Abstract

Many control applications pose optimisation problems with multimodal and nonsmooth cost functions. Gradient methods are ineffective in these situations. The adaptive simulated annealing (ASA) offers a viable optimisation tool for tackling these difficult constrained optimisation problems. We demonstrate the effectiveness of the ASA using an application, designing finite-precision PID controller structures with maximum stability robustness measure. The sparseness issue of controller structures is also discussed, and it is shown that the ASA can cope with this kind of constraints easily.

1 Introduction

Optimisation problems with multimodal and nonsmooth cost functions are commonly encountered in control applications. Gradient-based algorithms are ineffective in these applications due to the problem of local minima or the difficulty in calculating gradients. Optimisation methods that require no gradient and can achieve a global optimal solution offer considerable advantages in solving these difficult optimisation problems. Two classes of such global optimisation methods are the genetic algorithm (GA) [1]–[3] and the simulated annealing (SA) [4]–[6]. While the GA seems to have attracted considerable attention (e.g. [7]–[9]), the SA by contrast has not received similar interests.

The SA is an optimisation technique with some strikingly positive and negative features. An attractive feature of SA is that it is very easy to program and the algorithm typically has few parameters that require tuning. A serious drawback of SA is that the standard SA can be very slow, often requiring much more number of cost-function evaluations to converge, compared with a carefully designed and tuned GA. The ASA [10]–[14], also known as the very fast simulated reannealing, overcomes this drawback by using a much faster annealing schedule and adopting a reannealing scheme to adapt itself. The algorithm also maintains all the advantages of standard SA algorithms.

Controller implementations with fixed-point arithmetic offer the advantages of speed, memory space, cost and simplicity over floating-point arithmetic [15]. However, a designed stable closed-loop system may become unstable when the infinite-precision controller is implemented using a fixed-point processor due to finite-word-length (FWL) effects. This poses the problem of finding an optimal controller realization, which has a maximum tolerance to round-off error, by maximizing a stability robustness measure [16],[17]. For the PID controller structure, the problem can be solved as an optimisation problem with four variables [18],[19]. However, the optimisation criteria are nonsmooth and nonconvex functions. This offers an ideal testing case for applying the ASA.

It is desirable that a controller realization has a sparse structure, namely containing many elements of 0, 1 and -1. A true optimal controller realisation with a maximum stability bound is a fully parameterized structure and usually destroys the sparse structure. A sparse structure is particularly important for high-order controllers. Although a PID controller is a low-order one, we use it to illustrate that sparseness requirement can be imposed as simple constraints and the ASA can cope with these constraints easily.

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