Individual Evaluation Scheduling for Experiment-Based Evolutionary Multi-objective Optimization

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Abstract. Since the pioneer work of Evolution Strategies, experiment-based optimization is one of the promising applications of evolutionary computation. Recent progress in automatic control and instrumentation provides a smart environment called Hardware In the Loop Simulation (HILS) for such application. However, since optimization through experiment has severe condition of limited evaluation time and fluctuation of observation, we have to develop methodologies that overcome these problems. This paper discusses application of Multi-Objective Evolutionary Algorithms (MOEAs) to experiment-based optimization of control parameters of dynamical systems. In such applications, we have to apply various parameter candidates spreading near the Pareto frontier to the system, and it causes fluctuation of the observed criteria due to the transient response by parameter switching. For reduction of loss time caused by such transient response in evaluation of criteria, we propose techniques called Evaluation Order Scheduling and Evaluation Time Scheduling. Numerical experiments using a formal test problem and experiment in a HILS environment for real internal-combustion engines have demonstrated the effectiveness of the proposed methods.

1 Introduction

In these years, in automotive internal-combustion engines, their evaluation criteria such as environmental emissions (CO, HC, NO_x), fuel-consumption and engine torque, have to be balanced simultaneously at high level. To achieve such goals, many electronic control devices are mounted to the engines, and lots of parameters of the Engine Control Units (ECUs) have to be adjusted adequately. So far, this problem is solved by operator's manual calibration through experiment. However, to achieve higher engine performance on one hand and

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to enhance productivity of design process on the other, automatic design based on multi-objective optimization is needed. One candidate is simulation-based optimization. However, to construct a physical model of an internal-combustion engine in detail requires a lot of effort, and it is not cost effective.

Since the pioneer work of Evolution Strategies [1,12,14], experiment-based optimization[1] is one of the promising applications of evolutionary computation. Recent progress in automatic control and instrumentation provides a smart environment called Hardware In the Loop Simulation (HILS) for such application. However, since optimization through experiment has to be completed under severe restriction of evaluation time and fluctuation of observation, we have to develop methodologies that overcome these problems.

In this paper, we discuss an experiment-based Evolutionary Multi-objective Optimization (EMO) to calibrate control parameters of an automotive internal-combustion engine using HILS. We have proposed a MOEA for noisy fitness functions and a crossover operator for periodic functions [8,9] to overcome these problems. However, because conventional MOEAs have been studied for simulation-based optimization, no MOEAs proposed so far can handle the adverse effect of the system dynamics appropriately. In this paper, we propose Individual Evaluation Scheduling (IES) which is composed of Evaluation Order Scheduling (EOS) and Evaluation Time Scheduling (ETS) for MOEAs to overcome this problem by reducing loss time for waiting for diminishing of transient response of engine control caused by parameter switching. The EOS is constructed based on a local search method for the traveling salesman problem so as to reduce the total magnitude of change in the parameters among population. Additionally, the ETS is defined based on the Euclidean distances between individuals so as to provide adequate estimate of length of loss time to wait.

This paper is organized as follows. In Section 2, our current studies are introduced. In Section 3, to handle the system dynamics appropriately, individual evaluation scheduling for MOEAs is introduced. The results of a test function with dynamics and a real engine experiment are shown in Sections 4 and 5 respectively. As a result, it is shown that the proposed method improves search ability of MOEAs in experiment-based optimization of dynamical systems.

2 Current Studies

2.1 Experiment-Based Optimization Under Hardware in the Loop Simulation Environment

In recent automotive development, we can use a smart environment called Hardware In the Loop Simulation (HILS) for the experiment-based optimization, thanks to the progress of automatic control and instrumentation. The HILS is a technique for simulating a whole system by synchronizing a simulator with a real machine to evaluate the performance of a large-scale system accurately in advance.

[1] In this paper, the term of "experiment-based optimization" is used in the meaning of "the system parameters of a real system are optimized directly by optimization techniques in real time through experiments".