Acceleration of Experiment-Based Evolutionary Multi-objective Optimization Using Fitness Estimation

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Abstract. Evolutionary Multi-objective Optimization (EMO) is expected to be a powerful optimization framework for real world problems such as engineering design. Recent progress in automatic control and instrumentation provides a smart environment called Hardware In the Loop Simulation (HILS). It is available for our target application, that is, the experiment-based optimization. However, since Multi-objective Evolutionary Algorithms (MOEAs) require a large number of evaluations, it is difficult to apply it to real world problems of costly evaluation. To make experiment-based EMO using the HILS environment feasible, the most important pre-requisite is to reduce the number of necessary fitness evaluations. In the experiment-based EMO, the performance analysis of the evaluation reduction under the uncertainty such as observation noise is highly important, although the previous works assume noise-free environments. In this paper, we propose an evaluation reduction to overcome the above-mentioned problem by selecting the solution candidates by means of the estimated fitness before applying them to the real experiment in MOEAs. We call this technique Pre-selection. For the estimation of fitness, we adopt locally weighted regression. The effectiveness of the proposed method is examined by numerical experiments.

1 Introduction

In recent automotive engine development, a number of parameters of Engine Control Units (ECUs) mounted to engines have to be adjusted adequately to achieve higher engine performance. Because plural criteria such as environmental emissions (CO, HC, NO_x), fuel-consumption and engine torque need to be balanced at higher level, this operation called calibration becomes time-consuming and complex process year after year.

To attain such demanding goals, automatic design based on multi-objective optimization is needed as the new methodology that takes the place of conventional operator's manual calibration. Recent progress in automatic control and instrumentation provides a smart environment called Hardware In the Loop

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Simulation (HILS) for the calibration of control parameters of engines. The HILS environment is composed of a real engine and an engine test bed which can simulate vehicle running conditions using an ultra-low inertia dynamometer controlled by a computer. Applying Evolutionary Multi-objective Optimization (EMO) to the HILS environment is a promising field of application.

However, since the evaluation of the real engine experiment is costly, the requirement for many evaluation Multi-objective Evolutionary Algorithms (MOEAs) causes a serious problem, that is, tremendous optimization time. Parallelization is one of the solutions for real world problems which require enormous evaluation costs, but the parallelization of the HILS environment is not realistic choice in view of the installation cost and space. As another approach for the time consuming problems in the airfoil design using Computational Fluid Dynamics (CFD) [12] for instance, evaluation reduction methods for EAs have been studied actively[1]. In the past decade, main current of the evaluation reduction is to use statistical approximation model which is constructed by search histories of individuals evaluated in the real environment in the past . Generally speaking, because an evaluation cost of the approximation model is smaller enough than the real environment, it is possible to decrease the total evaluation time substantially.

To make experiment-based EMO using the HILS environment feasible, reduction of fitness evaluation is the most important requirement. However, the researches of the evaluation reduction method for MOEAs are still few compared with that for single objective EAs. Additionally, in our target application, that is, the experiment-based EMO for the real engine, the performance analysis of the evaluation reduction under uncertainty environments is highly important, although previous works [6,10,14,15] assume noise-free environment.

In this paper, we discuss a Pre-selection as an evaluation reduction method for the experiment-based EMO. To apply to the uncertainty environment such as HILS, we propose a general Pre-selection algorithm which can employ approximation modeling techniques having a robustness for observation noise. The algorithm is constructed in the manner that the offspring generated in the area having sparse distribution of non-dominated individuals in the archived population is preferentially selected. This paper is organized as follows. In Section 2, we introduce Locally Weighted Regression (LWR) [1] as an approximation modeling technique suitable for noise environment. In Section 3, we propose a general Pre-selection algorithm which does not depend on features of modeling techniques for MOEAs. Moreover, we examine effectiveness of the proposed method under noise-free and observation noise environments through numerical experiments in Section 4. Section 5 is the conclusion of this paper.

2 Background of Locally Weighted Regression

In conventional evaluation reduction for EAs, many researchers have employed many kinds of approximation modeling technique for fitness function. For

[1] See the detailed survey by Jin et al. [11].