Evolutionary Shape Optimization Using Gaussian Processes

Wenbin Song

School of Engineering Sciences, University of Southampton
University Road, Southampton SO17 1BJ, U.K.
w.song@soton.ac.uk

Summary. This chapter presents studies on structural shape optimization using evolutionary computation methods and Gaussian process based meta-modeling techniques. Methods of evolutionary computation have been used to solve design optimization problems in a wide range of areas in a process mimicking the evolution of biological life in natural world. Among various evolutionary computation methods, genetic algorithms have been attracting attentions due to its easiness to implement and its robustness in locating near global optimal solutions. However, the large number of iterations typically required by evolutionary search methods to converge has prompted research interests in the use of meta-models in the process. Gaussian process based meta-modeling technique is one of the popular choices since it not only can provide a prediction on the function value, but also can provide error estimate on the prediction. This chapter describes frameworks using genetic algorithms and Gaussian process based meta-modeling techniques for structural shape optimization problems. Application examples of such approaches are given in areas of firtree shape optimization using finite element method and engine nacelle optimization using computational fluid dynamics.

11.1 Introduction

The robustness in finding near-global optimal solutions using the evolutionary search methods, and in particular, genetic algorithms (GAs) [1], has attracted an increasing amount of research interests in the use of such methods in various optimization and design problems in fields such as engineering design, finance, and job scheduling [2–5]. GAs typically require large number of fitness evaluations for the results to converge to global optimal solutions. Therefore, improving the efficiency of GAs has become a key factor in their successful applications to real-world problems when fitness evaluations become computationally expensive. In structural shape optimization problems, high fidelity analysis codes, such as finite element and computational fluid dynamics, are often used to compute fitnesses of individuals in the population. This presents
particular challenge for the application of GAs to real-world structural shape optimization problems.

Two categories of techniques have been proposed to tackle the issue of efficiency of evolutionary search methods: the first is focused on devising more efficient variants of the canonical algorithms either by using a hybrid of local search and evolutionary methods or by using genetic operators customized to applications [6–9]. The former is also known as memetic algorithms which combine gradient based local search with GAs in the sense of Lamarckian or Baldwinian learning mechanisms [10]. The second type involves using metamodels, also called approximation models or surrogate models, in lieu of the exact and often expensive function evaluations [11]. One of the common features of these techniques is that both types of methods try to reduce the number of exact fitness evaluations to improve overall efficiency. As these two types of techniques can be easily combined to further speed up the process, research effort can be focused on them separately. The focus of the current chapter is on efficient frameworks for combining genetic algorithms with Gaussian process based approximation technique, which is also known as Kriging [12]. The emphasis is placed on devising effective frameworks which balance the needs for exploitation and exploration. The purpose of exploitation is to improve the accuracy of approximation models based on available data and the aim of exploration is to reliably locate optimal solutions on the approximation models.

Various strategies have been proposed and studied to tackle the use of meta-models in evolutionary frameworks in addition to researches into different meta-modeling techniques. For example, Ong [19] proposed the use of radial basis function (RBF) models in a trust region framework to reduce expensive function evaluations in local searches, which are combined with a genetic algorithm to assure global convergence. Song [14] illustrated the use of a 3σ update strategy in combining a global Kriging meta-model with GA on an industrial design problem. In addition to being used in expensive optimization studies, surrogate models also prove valuable in problems of multidisciplinary design where interactions between different disciplines can be studied more thoroughly using surrogates.

In the next section, different methods for building the meta-models are described to provide some background knowledge for commonly used approximation methods. Two frameworks incorporating these Gaussian process based meta-models in evolutionary search methods is described in section III. Two application examples are given in section IV. The first example involves the optimization of turbine blade firtree root using finite element method. The second example demonstrates the use of computational fluid dynamics on the shape optimization of civil aero-engine nacelle. A brief discussion is given at the end of the chapter.