A New Multiple Objective Evolutionary Algorithm for Reliability Optimization of Series-Parallel Systems

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ABSTRACT

A new multiple objective evolutionary algorithm is proposed for reliability optimization of series-parallel systems. This algorithm uses a genetic algorithm based on rank selection and elitist reinsertion and a modified constraint handling method. Because genetic algorithms are appropriate for high-dimensional stochastic problems with many nonlinearities or discontinuities, they are suited for solving reliability design problems. The developed algorithm mainly differs from other multiple objective evolutionary algorithms in the crossover operation performed and in the fitness assignment. In the crossover step, several offspring are created through multi-parent recombination. Thus, the mating pool contains a great amount of diverse solutions. The disruptive nature of the proposed type of crossover, called subsystem rotation crossover, encourages the exploration of the search space. The paper presents a multiple objective formulation of the redundancy allocation problem. The three objective functions that are simultaneously optimized are the maximization of system reliability, the minimization of system cost, and the minimization of system weight. The proposed algorithm was thoroughly tested and a performance comparison of the proposed algorithm against one well-known multiple objective evolutionary algorithms that currently exists shows that the algorithm has a better performance when solving multiple objective redundant allocation problems.

Keywords: Crossover Operation, Genetic Algorithms, Integer Chromosomal Representation, Multiple Objective Evolutionary Algorithms, Redundancy Allocation Problem, Series-Parallel System

INTRODUCTION

This paper describes the use of an evolutionary algorithm to the multiple objective redundancy allocation problem. The problem addressed in the paper arises in many real engineering optimization problems, where managers and/or decision-makers have to efficiently allocate components from a set of predefined component choices to determine the optimal configuration to be implemented. There are numerous application areas of the redundancy allocation problem, such as in the case of electrical power systems (Ouiddir et al., 2004), transportation...
systems (Levitin & Lisnianski, 2001), telecommunications (Lyu et al., 2001), among others.

This paper addresses the problem of designing a hardware system structure. In the problem formulation presented, there is a specified number of subsystems and, for each subsystem, there are multiple component choices which can be selected and used in parallel. This formulation pertains to the well-known redundancy allocation problem (RAP). In this paper, the RAP is modeled as a multiple objective problem with the system reliability to be maximized, cost, and weight of the system to be minimized, and no constraints limiting the possible values of reliability, making this problem a multiple objective combinatorial optimization (MOCO) problem.

The proposed algorithm represents a new alternative for the solution of a difficult MOCO reliability design problem. This new approach has the strength of a problem-oriented technique. The selection of components is advantageously combined to create a multiple objective evolutionary algorithm (MOEA) which can tackle the problem in the most efficient way. Since MOCO problems contain information derived from their specific combinatorial structure, this can be advantageously exploited during the search. To take advantage of the combinatorial structure within the search algorithm, a problem-dependent crossover operator is used, called the subsystem rotation crossover (SURC).

To be most efficient, the solution of a multiple objective problem seems to necessarily require a hybrid algorithm, i.e., an integration of standard evolutionary algorithms and problem dependent components. This is particularly true for MOCO problems, where the adaptation of a universal method to a problem cannot compete with a method specifically designed for this problem.

This paper is structured as follows. In the next section, a review of multiple objective optimization is presented. Some of the existent MOEAs and the desired characteristics that most MOEAs try to achieve are discussed. The RAP and a review of some of the research that has been done to solve the RAP is then introduced.

The following section presented the proposed algorithm. An example and a performance comparison of the developed algorithm against one of the most well-known MOEAs that currently exists are also given. Finally, the paper concludes with a summary.

**MULTIPLE OBJECTIVE OPTIMIZATION**

Multiple objective optimization refers to the solution of problems with two or more objectives to be satisfied simultaneously. Often, such objectives are in conflict with each other and are expressed in different units. Because of their nature, multiple objective optimization problems normally have, not one, but a set of solutions, which are called Pareto-optimal solutions or nondominated solutions (Chankong & Haimes, 1983; Hans, 1988). When such solutions are represented in the objective function space, the graph produced is called the Pareto front or the Pareto-optimal set of the problem.

In general, there are two primary approaches for the solution of a multiple objective problem. The first approach involves determining the relative importance of the attributes, and aggregating the attributes into some kind of overall composite objective function (sometimes called a value or utility function); while the second approach involves populating a number of feasible solutions along a Pareto frontier and the final solution is a set of non-dominated solutions. MOEAs are the most notable methods from this second approach.

A general formulation of a multiple objective optimization problem consists of a number of objectives with a number of inequality and equality constraints. Mathematically, the problem can be written as in Equation 1 (Rao, 1991):

\[
\text{minimize} / \text{maximize } f(x) \quad (1)
\]

subject to:

\[
g_j(x) \leq 0 \quad j = 1, 2, \ldots, J
\]

\[
h_k(x) = 0 \quad k = 1, 2, \ldots, K
\]
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