Particle Evolutionary Swarm for Design Reliability Optimization

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Abstract. This papers proposes an enhanced Particle Swarm Optimization algorithm with multi-objective optimization concepts to handle constraints, and operators to keep diversity and exploration. Our approach, PESDRO, is found robust at solving redundancy and reliability allocation problems with two objective functions: reliability and cost. The approach uses redundancy of components, diversity of suppliers, and incorporates a new concept called *Distribution Optimization*. The goal is the optimal design for reliability of coherent systems. The new technique is compared against algorithms representative of the state-of-the-art in the area by using a well-known benchmark. The experiments indicate that the proposed approach matches and often outperforms such methods.

1 Introduction

The reliability of any device is very important for manufacturers and users. Larger reliability of the final product is desired but, the consequent rise in production cost has negative effects on the user's budget. Therefore, the design reliability optimization problem is phrased as reliability improvement at a minimum cost. The common sense perception of reliability is the absence of failures. Therefore, reliability is sometimes referred to as "quality in time dimension", because is determined by the failures that may or may not occur to the product during its life span. The design reliability problem is hard and challenging, mainly due to the interaction of many subsystems whose conflicting local goals must contribute to the overall performance. New product design involves the specification of performance requirements, the evaluation and selection of components that perform some defined function, and the determination of the system level architecture.

The problems of interest to us are the redundancy and reliability allocation problems. There are two conflicting goals in them: reliability, and cost. The allocation problem is characterized by a large combinatorial search space, ruled by multiple design constraints.

Several optimization approaches have previously been used to solve the reliability allocation problem [1]. We introduce a new approach based upon the

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Particle Swarm Optimization (PSO) paradigm which was originally proposed by Kennedy and Eberhart [2]. Our approach, based on multi-objective optimization concepts (treats constraints as objective functions), includes: a selection criteria based on feasibility rules; a local-best PSO with ring topology organization; and two perturbation operators aimed to keep diversity.

The remainder of this paper is organized as follows. In Section 2, we introduce the problem of interest. Section 3 introduces our proposed approach. In Section 4, we describe a benchmark of 3 test functions. Section 5 provided a comparison of results with respect to techniques representative of the state-of-the-art in the area. Finally, our conclusion and future work are provided in Section 6.

2 System Reliability Optimization

As noted before, the redundancy and allocation problem deals with the optimization of reliability and cost. Frequently, this problem is described as optimal reliability design, subject to cost and weight constraints. Thus, cost and weight constraints are also optimized during the process. The optimization criterion could be posed in two different forms:

– Maximization of system reliability, subject to cost and weight constraints.
– Minimization of system cost, subject to reliability and weight constraints.

The reliability of a product at time t, $R(t)$, is the probability that it works like foresaw, during the time interval $(0, t]$; under several operational conditions and environment. The distribution of the time to failure of a product, determines its $R(t)$ reliability at time t.

$$R(t) \;=\; 1 - F(t) \;=\; P(T > t) \qquad t > 0 \tag{1}$$

where T is the time to failure and $F(t)$ is the cumulative distribution function. $F(t)$ thus denotes the probability that the unit fails within the time interval $(0, t]$.

The reliability of a product with several components is calculated using its structure function. Figure 1 shows the three kind of structures used to model the system's components of this paper.

Each system has its own structure function. The general structure functions for series and parallel structures are shown in Equations 2 and 3, where n is the number of components. The Equation 4 presents the structure function of a k-out-of-n system with n identical components, where k is the minimum number of components required for a system to work.

– Series

$$R_S = \prod_{i=1}^{n} R_i \tag{2}$$

– Parallel

$$R_S = 1 - \prod_{i=1}^{n} (1 - R_i) \tag{3}$$