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Population size influence on the efficiency of evolutionary algorithms to design water networks

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Abstract

The optimal sizing in water distribution networks (WDN) is of great interest because it allows the selection of alternative economical solutions that ensure design requirements at nodes (demands and pressure) and at lines (velocities). Among all the available design methodologies, this work analyzes those based on evolutionary algorithms (EAs).

EAs are a combination of deterministic and random approaches, and the performance of the algorithm depends on the searching process. Each EA features specific parameters, and a proper calibration helps to reduce the randomness factor and improves the effectiveness of the search for minima. More specifically, the only common parameter to all techniques is the initial size of the random population (P). It is well known that population size should be large enough to guarantee the diversity of solutions and must grow with the number of decision variables. However, the larger the population size, the slower the convergence process.

This work attempts to determine the population size that yields better solutions in less time. In order to get that, the work applies a method based on the concept of efficiency (E) of an algorithm. This efficiency relates the quality of the obtained solution with the computational effort that every EA requires to find the final design solution. This ratio E also represents an objective indicator to compare the performance of different algorithms applied to WDN optimization.

The proposed methodology is applied to the pipe-sizing problem of three medium-sized benchmark networks, such as Hanoi, New York Tunnel and GoYang networks. Thus, from the currently available algorithms, this work includes evolutionary methodologies based on a Pseudo-Genetic Algorithm (PGA), Particle Swarm Optimization (PSO) and Harmony Search (HS).

First, the different algorithm parameters for each network are calibrated. The values used for every EA are those that have been calculated in previous works. Secondly, specific parameters remain constant and the population size is modified. After more than 500,000 simulations, the influence of the population size is statistically analyzed in the final solutions. Finally, the efficiency was analyzed for each network and algorithm. The results ensure the best possible configuration based on the quality of the solutions and the convergence speed of the algorithm, depending of the population size.

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1. Introduction

The optimal lay-out, design and operation of water distribution networks (WDN) is of central importance to water industries and governments due to the vast capital investments associated with these tasks. While these problems are not independent of each other, they can be formulated and solved independently. This work is focused on the design, namely in the optimal sizing of pipes in WDN, ensuring requirements of demands and pressure at the nodes, and velocities at the lines.

This problem is normally interpreted as a NP-hard [1] problem mainly due to two reasons: nonlinear equations and discrete-valued diameters. A large variety of optimization methodologies have been developed for this problem, including approaches that reduce the complexity of the original nonlinear problem to facilitate the use of linear and nonlinear programming [2].

More recently, intelligent optimization techniques as Evolutionary Algorithms (EAs) have found applications in this area. The generic term "evolutionary computation" refers to a broad set of metaheuristic techniques to solve complex problems that base their performance on a similar mechanism to the processes of natural evolution. Besides, EAs have the advantage of being insensitive to the characteristics of the problem, so that since their introduction and subsequent popularization, EAs have been frequently used as an alternative optimization tool to conventional methods and have been successfully applied in a variety of areas, including optimization of WDN [3–6].

These techniques are based on the natural processes of evolution, using mechanisms to select the best combinations of the decision variables and to generate new solutions by recombination. It is because of that EAs require of setting the values of several algorithm components and parameters. The calibration of these parameters has a key influence on performance and efficacy of the algorithm [7,8].

The form and operation of some EAs are extensively studied, and one of the main conclusions is that the optimal value for these parameters is not universal for all problems, but it depends on the optimization problem and on the computational effort that will be spend in solving the problem. All EAs share some basic principles, but each has its own parameters, which guide the search algorithm to the best possible solution. Among all the parameters, the initial population size is the only one that can be considered common to all these techniques, and probably it has been one of the important topics to consider in evolutionary computation.

In this regard, it is possible to find different results in the literature on what may be the appropriate size of population in an optimization process [9,10]. Since the exploration capacity of the algorithm depends on the population diversity, researchers usually argue that a small population size could guide the algorithm to poor solutions, while a large population size could lead the algorithm to a computational time too high in finding a final solution. For this reason, in choosing the population size a trade-off between solution quality and search time should be done.

This paper applies an efficiency rate (E) to the initial population size of the algorithm. E relates the quality of the solution obtained to the computational effort involved to reach that solution. E has been calculated for the results obtained by three EAs for the pipe-sizing problem of three benchmarking networks. The selected algorithms include a PseudoGenetic Algorithm (PGA), a modified Particle Swarm Optimization Algorithm (PSO) and a Harmony Search Algorithm (HS). The different stages of the optimization process and the complete description of each EAs can be found in [7,5,11].

The presented method identify the most efficient population size for each of the analysed algorithms, and it can be applied to many other EAs and networks that have not been considered in this work.