Improved Evolutionary Algorithm Optimisation of Water Distribution Systems Using Domain Knowledge

by
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Thesis submitted to School of Civil, Environmental & Mining Engineering
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in fulfillment of the requirements for
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Doctor of Philosophy

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Abstract

Water distribution systems (WDSs) are becoming increasingly complex and larger in scale due to the rapid growth of population and fast urbanization. Hence, they require high levels of investment for their construction and maintenance. This motivates the need to optimally design these systems, with the aim being to minimize the investment budget while maintaining high service quality. Over the past 25 years, a number of evolutionary algorithms (EAs) have been developed to achieve optimal design solutions for WDSs, representing a focal point of much research in this area.

One issue that hinders EAs' wide application in industry is their significant demand on computational resources when handling real-world WDSs. In recognition of this, there has been a move from aiming to find the globally optimal solutions to identifying the best possible solutions within constrained computational resources. While many studies have been undertaken to attain this goal, there have been limited efforts that use engineering knowledge to reduce the computational effort. The research undertaken in this thesis is such an attempt, as it aims to efficiently identify near-optimal solutions with the aid of WDS design knowledge.

This thesis presents a domain-knowledge based optimization framework that enables the near-optimal solutions (fronts) of WDS problems to be identified within constrained computing time. The knowledge considered includes (i) the relationship between pipe size and distance to the water source(s); (ii) the impact of flow velocities on optimal solutions; and (iii) the relationship between flow velocities and network resilience.

This thesis consists of an Introduction, three chapters that are based around a series of three journal papers and a set of Conclusions and Recommendations for Further Work.

The first paper introduces a new initialization method to assist genetic algorithms (GAs) to identify near-optimal solutions in a computationally efficient manner. This is attained by incorporating domain knowledge into the generation of the initial population of GAs. The results show that the proposed method performs better than the other three initialization methods considered, both in terms of computational efficiency and the ability to find near-optimal solutions.

The second paper investigates the relative impact of different algorithm initializations and searching mechanisms on the speed with which near-optimal solutions can be identified for large WDS design problems. Results indicate that EA parameterizations, that emphasize exploitation relative to exploration, enable near-optimal solutions to be identified earlier in the search, which is due to the “big bowl” shape of the fitness function for all of the WDS problems considered. Using initial solutions that are informed using domain knowledge can further increase the speed with which near-optimal solutions can be identified.

The third publication extends the single-objective method in the first paper to a two-objective problem. The objectives considered are the minimization of cost and maximization of network resilience. The performance of the two-objective initialization approach is compared with that of randomly initializing the population of multi-objective EAs applied to range of WDS design problems. The results indicate that there are considerable benefits in using the proposed initialization method in terms of being able to identify near-optimal fronts more rapidly.

Although all of the results obtained in this research have shown that the proposed method is effective for improving the efficiency of EAs in finding near-optimal solutions, only gravity fed water distribution systems with a single loading case were considered as case studies. One important area for future research is the extension of the proposed method to more complex WDSs which may include tanks, pumps and valves.

Statement of Originality

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List of Acronyms

ABS	Average of the best solutions
BBS	Best of the best solutions
DE	Differential evolution
DMO	Deviation of the mean cost relative to the best known solution
EA	Evolutionary algorithms
GA	Genetic algorithm
KLSM	Kang and Lansey's sampling method
LHS	Latin hypercube sampling
MOEA	Multi-objective evolutionary algorithms
MOPHSM	Multi-objective prescreened heuristic sampling method
NYTP	New York tunnel problem
PCX	Patent-centric crossover
PHSM	Prescreened heuristic sampling method
RS	Random sampling
SBX	Simulated binary crossover
SPD	Standardized average population diversity
SPX	Simplex crossover
UM	Uniform mutation
UNDX	Unimodal normal distribution crossover
WDS	Water distribution systems