Advanced Hybrid Approaches Based on Graph Theory Decomposition, Modified Evolutionary Algorithms and Deterministic Optimisation Techniques for the Design of Water Distribution Systems

by
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Thesis submitted to School of Civil, Environmental & Mining Engineering
of the University of Adelaide
in fulfillment of the requirements for
the degree of

Doctor of Philosophy

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Abstract

The cost of water distribution system (WDS) design or rehabilitation is normally expensive. Over the past 40 years, a number of optimization[1] techniques have therefore been developed to find optimal designs for WDSs in order to save costs, while satisfying the specified design criteria. Often there are a large number of decision variables involved. The majority of currently available optimization techniques exhibit limitations when dealing with large WDSs. Two limitations include (i) finding only local optimal solutions and/or (ii) exhibiting computational inefficiency. The research undertaken in this dissertation has focused on developing advanced optimization techniques that are able to find good quality solutions for real-world sized or large WDS design or rehabilitation strategies with great efficiency. There were three objectives for the research: (i) the modification and improvement of currently available optimization techniques; (ii) the development of advanced hybrid optimization techniques (evolutionary algorithms combined with traditional deterministic optimization techniques) and (iii) the proposal of novel optimization methods with the incorporation of graph decomposition techniques.

The most novel feature of this research is that graph decomposition techniques have been successfully incorporated to facilitate the optimization for WDS design. A number of decomposition techniques have been developed to decompose WDSs by the use of graph theory in this research. Real-world sized or large WDSs are used to demonstrate the effectiveness of the proposed advanced optimization techniques described in this thesis. Results show that these advanced methods are capable of obtaining sound optimal solutions with significantly improved efficiency compared to currently available optimization techniques. The main contribution of this thesis is

[1] American spelling has been used in this thesis as all the publications included in this thesis have been submitted to or published in American journals.

the provision of effective and efficient optimization techniques for real-world sized or large WDS designs or rehabilitation problems.

Statement of Originality

I **Feifei Zheng** hereby declare that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution. To the best of my knowledge and belief in contains no material previously published or written by another person, except where due reference has been made in the text.

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Journal Papers Published as Part of This Thesis Research:

Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2011a). "A combined NLP-differential evolution algorithm approach for the optimization of looped water distribution systems." *Water Resources Research*, 47(8), W08531.

Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2011b). "Dynamically expanding choice-table approach to genetic algorithm optimization of water distribution systems." *Journal of Water Resources Planning and Management*, 137(6), 547-551.

Zheng, **F**., A. C. Zecchin and A. R. Simpson (2012a). "A self adaptive differential evolution algorithm applied to water distribution system optimization." *Journal of Computing in Civil Engineering*, doi:10.1061/(ASCE)CP.1943-5487.0000208.

Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2012d). "A decomposition and multi-stage optimization approach applied to the optimization of water distribution systems with multiple supply sources." *Water Resources Research*, doi:10.1029/2012WR013160.

Zheng, **F**., A. R. Simpson, A. C. Zecchin, M. F. Lambert (2013). "A non-crossover dither creeping mutation genetic algorithm for pipe network optimization." *Journal of Water Resources Planning and Management*, doi: 10.1061/(ASCE)WR.1943-5452.0000351.

Acknowledgements

I would take this opportunity to acknowledge the support and guidance of my academic supervisors Prof. Angus R. Simpson and Dr. Aaron C. Zecchin. I appreciate the research freedom I have enjoyed under their supervision. I thank them deeply for always being available to provide constructive suggestions and discuss any issues with great patience.

I would express my appreciation to School Editor Barbara Brougham for her assistance. I would also like to acknowledge the school staff and postgraduate students for their help and company over the past three years.

I would like to acknowledge the support of my family. To my wife Weiwei Bi for her love, patience and continuous support. This dissertation is as much as indirect product of her as it is a direct product of me. To my bother Bingbing Zheng for his help and encouragement. To my parents and my parents-in-law for their love and encouragement.

I acknowledge the research scholarship provided by Australian government and the University of Adelaide.

List of Publications

The following publications were produced from the research associated with the work presented within this thesis.

Journal papers:

[1] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2011a). "A combined NLP-differential evolution algorithm approach for the optimization of looped water distribution systems." *Water Resources Research*, 47(8), W08531.

[2] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2011b). "Dynamically expanding choice-table approach to genetic algorithm optimization of water distribution systems." *Journal of Water Resources Planning and Management*, 137(6), 547-551.

[3] Zheng, **F**., A. C. Zecchin and A. R. Simpson (2012a). "A self adaptive differential evolution algorithm applied to water distribution system optimization." *Journal of Computing in Civil Engineering*, doi:10.1061/(ASCE)CP.1943-5487.0000208.

[4] Zheng, **F**., A. R. Simpson, A. C. Zecchin and J. Deuerlein (2012b). "A graph decomposition based approach for water distribution network optimization." *Water Resources Research*, submitted June 2012.

[5] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2012c). "A combined binary linear programming and differential evolution algorithm approach for water distribution system optimization." *Journal of Water Resources Planning and Management*, submitted June 2012.

[6] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2012d). "A decomposition and multi-stage optimization approach applied to optimization of water distribution systems with multiple sources." *Water Resources Research*, doi:10.1029/2012WR013160.

[7] Zheng, **F**., A. R. Simpson, A. C. Zecchin, M. F. Lambert (2013). "A non-crossover dither creeping mutation genetic algorithm for pipe network optimization." *Journal of Water Resources Planning and Management*, doi: 10.1061/(ASCE)WR.1943-5452.0000351.

Conference papers:

[1] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2010). "A method for assessing the performance of genetic algorithm optimization for water distribution design." *Proc., Water Distribution System Analysis* 2010 *(WDSA*2010*)*, ASCE, Tucson, AZ, USA.

[2] Zheng, **F**., A. R. Simpson, and A. Zecchin (2011c). "Performance study of differential evolution with various mutation strategies applied to water distribution system optimization." *Proc., World Environmental and Water Resources Congress* 2011, ASCE, Palm Springs, California.

[3] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2011d). "Optimal rehabilitation for large water distribution systems using genetic algorithms." *Proc., Australia Water Association (AWA) OzWater* 2011, Adelaide, SA, Australia.

[4] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2011e). "Parametric analysis of differential evolution algorithm applied to water distribution system optimization." *Proc., 11th International Conference on Computing and Control for the Water Industry (CCWI* 2011*)*, Exeter, UK.

[5] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2012e). "A performance comparison of differential evolution and genetic algorithm variants applied to water distribution system optimization." *Proc., World Environmental & Water Resources Congress (EWRI* 2012*)*, Albuquerque, New Mexico.

[6] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2012f). "A new hybrid optimization model for water distribution system optimization." *Proc., Water Distribution System Analysis* 2012 *(WDSA* 2012*)*, ASCE, Adelaide, SA, Australia.

[7] Zheng, **F**., A. R. Simpson, and A. C. Zecchin (2012g). "A performance comparison between differential evolution variants and genetic algorithms for water network optimization." *Proc., Water Distribution System Analysis* 2012 *(WDSA* 2012*)*, ASCE, Adelaide, SA, Australia.