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A tool for practical simplification of water networks models

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Abstract

This paper presents development of water network model reduction software, Simplifier2. The application can be integrated with other concepts applied to water distribution system or it can be used as a standalone tool for the purpose of the model simplification only. The utilisation of parallel programming techniques and sparse matrices ordering algorithms drastically increased the speed of simplification. Simplifier2 is able to reduce the water network model, consisting of several thousand elements, in less than 1 minute calculation time. Simplifier2 has been already successfully utilised in a number of research and commercial projects.

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Keywords: simplification; tool; water distribution systems;

1. Introduction

Nowadays it is common that models of water distribution system (WDS) can consist of thousands of elements to accurate replicate the hydraulic behaviour of a real WDS. This approach is appropriate for simulation purposes, however online optimisation tasks are much more computationally demanding and simplified models are needed. [39] proposed a mathematical method for the reduction of WDS models described by a large-scale system of nonlinear differential algebraic equations. This procedure has an advantage compared to other methods because the reduced model preserves the nonlinearity of the original network and approximates its operation accurately under different conditions. The method was recently extended in [22] and incorporates the energy audits concepts [6] in order to preserve the energy distribution of the WDS model. The simplified model resembles the energy distribution of original model due to imposing new pressure constraints on the retained consumption nodes. This will prevent a situation where the pump speed required to satisfy minimum pressure constrains is different for the reduced model and the original.

This papers presents development of the model reduction software, Simplifier2, based on the extended simplification algorithm. Simplifier2 could be integrated with other concepts applied to the WDS or it can be used as a standalone tool for the purpose of the model simplification only. Simplifier2 has been already successfully utilised in a number of research and commercial projects, see e.g. [36,37].

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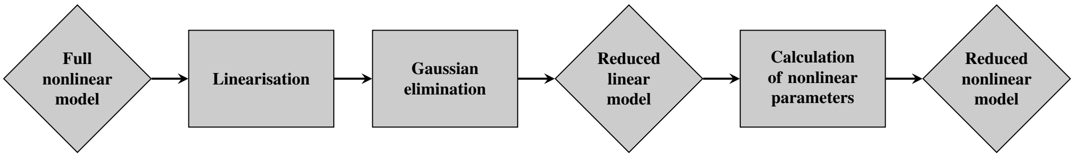

Fig. 1. The variable elimination algorithm.

Section 2 provides a brief description of techniques for WDS model simplification, in particular the variables elimination method. Section 3 gathers all the tools utilised to carry out the implementation. Section 4 outlines the implementation process. Section 5 focuses on the computational aspects arisen throughout the software development. Section 6 briefly describes the features of Simplifier2. Finally, Section 7 concludes this paper.

2. Simplification of water networks models

There are different techniques of a WDS model reduction; the outcome of most of these methods is a hydraulic model with a smaller number of components than the prototype. The main aim of the reduced model is to preserve the nonlinearity of the original network and approximate its operation accurately under different conditions. The accuracy of the simplification depends on the model complexity, purpose of simplification and the selected method such as skeletonization [40], parameter-fitting [2], graph decomposition [9], enhanced global gradient algorithm (EGGA) [16], metamodelling [5] and variables elimination [22,39]. A systematic review of the aforementioned techniques, conducted by [21], recommended the variables elimination as fast, practical and robust technique for simplification of water network models.

2.1. Variable elimination algorithm

The variables elimination method is based on a mathematical formalism initially proposed by [39] and recently extended by [22]. This mathematical method enables reduction of water network models described by a large-scale system of nonlinear differential algebraic equations. The algorithm is illustrated in Figure 1 and proceeds through the following steps: full nonlinear model formulation, model linearisation at specified operation time, linear model reduction using Gaussian elimination and nonlinear reduced model reconstruction. The detailed description of the algorithm is omitted here as it can be found in [1,21]. The approach was successfully implemented and tested on many water networks, e.g. [4,24–26,28–30,35–37]. However, most of the implementations were suited for the particular application, hence no software tool exists that can be either embedded into a larger scheme or used standalone. The motivation behind the work described in this paper, was to create a tool that can be used by water distribution systems community for many purposes. The process of development and numerical enhancements to the method are given in the next sections.

3. Tools and software employed

Development of Simplifier2 was carried out with utilisation of the Microsoft Visual Studio 2010 package. Visual Studio 2010 comes with an integrated support for the .NET 4.0 framework, which enhanced the parallel programming by providing a new runtime, new class library types and new diagnostic tools [20]. These features allowed implementation of the scalable parallel C# code without having to work directly with threads or a thread pool, thereby provided means for improving the performance of numerical calculations.

The input data for the model reduction algorithm are water network topology and simulated hydraulic behaviour of the considered water distribution network. For this purpose the open-source Epanet2 Toolkit [32] was used as a hydraulic simulator to perform an extended period simulation of WDS hydraulic behaviour. The library consists of set of procedures that allow to run/stop simulation, modify simulation and network parameters and read/save the simulation data. The Epanet2 Toolkit provided also a compatibility with ".inp" (INP) format as it is a commonly