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INTERACTIVE 3D VISUALISATION OF OPTIMISATION FOR WATER DISTRIBUTION SYSTEMS

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This project investigates the use of modern 3D visualisation techniques to enable the interactive analysis of water distribution systems with the aim of providing the engineer with a clear picture of the problem and thus aid the overall design process. Water distribution systems are complex entities that are difficult to model and optimise as they consist of many interacting components each with a set of considerations to address, hence it is important for the engineer to understand and assess the behaviour of the system to enable its effective design and optimisation. This paper presents a new three-dimensional representation of pipe based water systems and demonstrates a range of innovative methods to convey information to the user. The system presented not only allows the engineer to visualise the various parameters of a network but also allows the user to observe the behaviour and progress of an iterative optimisation method. This paper contains examples of the combination of the interactive visualisation system and an evolutionary algorithm enabling the user to track and visualise the actions of the algorithm down to an individual pipe diameter change. It is proposed that this interactive visualisation system will provide engineers an unprecedented view of the way in which optimisation algorithms interact with a network model and may pave the way for greater interaction between engineer, network and optimiser in the future.

INTRODUCTION

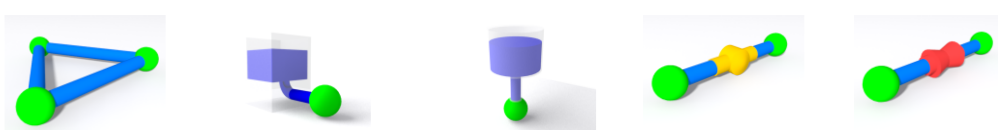
Water Distribution Networks (WDNs) are multifaceted systems that require a large amount of consideration when in the design phase. With so many factors to consider when designing a WDN it is important for the engineer to understand and assess the behaviour of the system to enable its effective design and optimisation. There are an increasing number of tools available to water system engineers for use in the design of pipe based distribution networks including both commercial and public domain software, each employing different network mapping techniques. Although three-dimensional mapping is becoming more popular in recent years, two dimensional mapping is still a commonly utilised method of WDN visualisation. Two dimensional visualisation solutions such as EPANET 2 have the ability to display a relatively limited amount of system information to the user at any one time, primarily relying on element colour to convey network statistics. However, representing a WDN in a three dimensional domain can inherently communicate more concurrent information to the user than in a 2D domain. The conveyance of information such as topographic relief and pipe diameter can be achieved using geometric assets, allowing colour mapping and other texture based techniques to display further system information.

In this paper we present the development of an interactive software package for the visualisation and optimisation of water distribution systems called WDNet3D. WDNet3D utilises a three dimensional domain to represent pipe based water distribution networks to effectively convey relevant hydraulic information to the user. In addition to presenting hydraulic data, the system can also be used to visualise the progress of an iterative optimisation technique such as a Genetic Algorithm (GA)[1] a popular technique when solving the problem of least-cost water distribution design[2]. This gives the engineer an insight into the actions of the algorithm and enables a greater understanding not only of the optimisation process, but of the aspects of the problem that are more difficult for the algorithm to solve.

WDNET3D

When developing WDNet3D it was important to provide the user with an intuitive yet powerful method of navigating the 3D environment, this is especially important when traversing large and complex networks. The software employs a middle mouse button centric control method for viewport manipulation where the user can pan, orbit and dolly the viewport camera to explore the 3D domain. This type of camera navigation is utilised in a number of 3D computer graphics programs including Autodesk 3ds Max and has been shown to be an effective and intuitive control method.

It is important that system information is conveyed to the user in an effective manner, to facilitate this, the key principles of display design presented by Wickens et al. [3] were consulted when designing the geometry that would represent the network elements and variable communication methods. It is accepted that the user's perception and interpretation of signals is based on past experiences therefore the core network elements shown in Figure 1 were initially inspired by the classic network component representation utilised in EPANET's 2D graphical display. It was important to keep the elements simple but distinct so that specific components of a complex network could be identified quickly and with ease. As with other WDN mapping software such as EPANET 2, WDNet3D utilises a node & link based representation method where all network element fall into the category of either a node or link.



Junction & Pipe *Reservoir* *Tank* *Pump* *Valve*

Figure 1. WDNet3D Three Dimensional Network Element Representation

Hydraulic values and other network parameters can be displayed to the user using a variety of methods, such as element colour, size, texture and movement. For example, when displaying hydraulic pressure at a junction the software utilises the HCI principal of redundancy gain by conveying the pressure not only with colour, but also with element size shown in Figure 2, thus reinforcing the user's perception of the data being communicated.

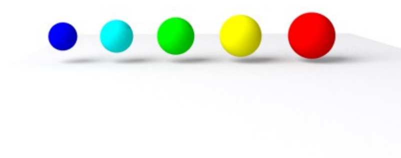


Figure 2. Redundancy Gain Value Representation for Junctions

The user has the ability to interact with a water system by clicking on any network element within the network. Doing so will display that object's hydraulic and optimisation information and enable the user to manipulate other parameters, for example junction demand, pipe roughness or pump speed.

WDNet3D utilises the junction coordinate and elevation data provided in a standard EPANET 2 input file to build and display a network. Pipes are drawn between connecting nodes/junctions and the diameters displayed accordingly. The data is normalised and adjusted to ensure all network element are visible and correctly displayed. The program is able to display large networks consisting of thousands of nodes and links and still give the user a good representation of the network topology.

Figure 3. EXNET [4] Rendered in WDNet3D

Figure 3 shows EXNET [4], a large water distribution network based on a real-world system rendered in WDNet3D. Note it is easy to identify pipe grouping and transmission mains and to get an immediate impression of the topology of the network.

WDNet3D utilises the EPANET 2 Programmer's Toolkit for hydraulic and water quality modelling, allowing solutions to be assessed so that relevant data can be passed to the visualisation component of the software. The interactive 3D visualisation module of the application is implemented using Panda3D, a rendering engine which is coded in C++.

THE VISUALISATION OF WDN OPTIMISATION

WDNet3D not only allows the engineer to visualise the various parameters of a network but also allows the user to observe the behaviour and progress of an optimisation method, such as a Genetic Algorithm (GA). Such algorithms have been widely used to optimise many complex engineering problems including the least cost design of water distribution networks[5][6]. Combining such an optimisation method with this visualisation system enables the user to track and visualise the actions of the algorithm down to an individual pipe diameter change. To achieve this WDNet3D aggregates changes made to the network over a GA run and displays them on the network model using a colour scale.

Figure 4 shows the Hanoi network displayed in WDNet3D after a GA optimisation run. The algorithm employed by WDNet3D is a standard steady-state GA utilising standard tournament selection, single point crossover, bitwise mutation and conditional worst individual replacement. The number of diameter changes between the first generation and final best solution during the optimisation process is displayed using a colour key on each pipe, where blue indicates low diameter variance and red high diameter variance.

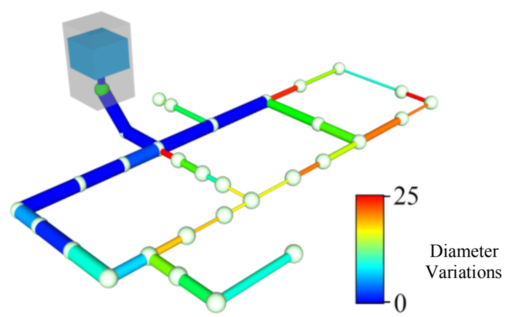


Figure 4. Pipe Diameter Changes for the Hanoi Problem

It can be observed that the larger pipes (dark blue) closest to the reservoir have not been frequently altered during the optimisation process whereas the small diameter pipes (red) towards the extremities of the network have had their diameters varied more frequently. This behaviour can be expected as diameter changes to the pipes near the reservoir would have a more significant effect on the hydraulic performance of the network than changes to pipes further down-stream.

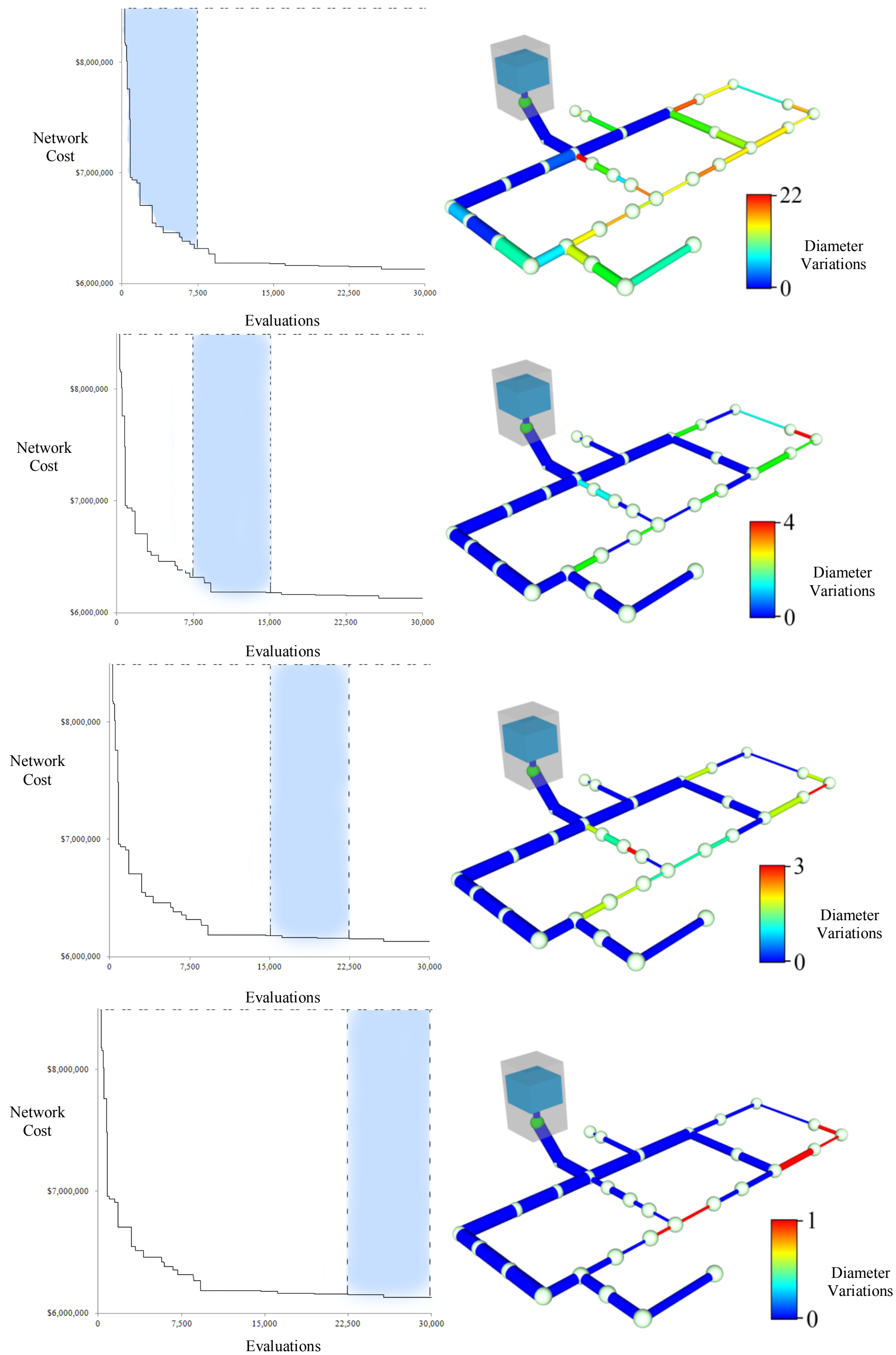


Figure 5. Best Solution Network Cost – Pipe Diameter Variations - Hanoi Problem

WDNet3D allows the user to pause the GA optimisation at any point in a run and view the algorithm's progress and behaviour. Figure 5 shows the performance of the GA over 30,000 solution evaluations with the pipe diameter variance displayed at four highlighted periods (light blue). It can be clearly seen from this figure that the algorithm settles on a set of sizes for the 'trunk mains' of this problem early on in the optimisation and that these diameters remain relatively fixed for the remainder of the optimisation. As time progresses, more of the network becomes fixed and the optimisation focuses on making changes to the extremities of the network. It can be observed that from the second period (7,500 evaluations) of the search onward, more than half (17+) of the pipes in the network have reached their final diameter and will not be changed for the remainder of the search. As this is showing the progression of the best individual, it is perhaps not surprising that the solution becomes progressively more fixed as the algorithm converges towards a solution. However, the key is that the spatial distribution of diameter changes can be seen across the network and can help identify areas that are proving difficult for the algorithm to optimise. An additional benefit of this approach is that it suggests that portions of the design that are fixed early on could be removed from the optimisation process and therefore reduce the number of mutations that lead to poorer results in the latter stages of an optimisation.

CONCLUSION

In this paper, we have presented the development of WDNet3D, an interactive three dimensional program for the visualisation of optimisation for water distribution systems. By drawing upon the key principals of human-computer interaction an effective and intuitive tool for the visualisation of water distribution systems has been developed. The system not only allows the engineer to visualise the various parameters of a network but also allows the user to observe the behaviour and progress of an iterative optimisation method. The 3D visualisation and the use of colour allows the system to make good use of the screen 'real estate' and to communicate large amounts of information to the user in a single snapshot. For example, the 3D system means that both diameter and relative elevation are implicitly presented before colour is used to show the various hydraulic parameters. The presentation is also more naturally interpreted by the user than viewing diameters and elevations of links and nodes as colours or floating point values.

In addition, the system has been shown to aggregate changes to the network over a genetic algorithm run and 'lift the lid' on the operations of a genetic algorithm as it is optimising a network. The link between genotype and phenotype spaces in evolutionary algorithm optimisation is often not well explained, particularly for real-world problems. WDNet3D demonstrates that for WDN optimisation, it is possible to gain an understanding of the spatial distribution of algorithm behaviour on this problem.

With further development WDNet3D will not only display the operations of an optimisation method but also enable the algorithm's search to be automatically constrained. From the observations made when visualising pipe diameter variation during an optimisation run it was noted that a large proportion of pipe diameters in a network are finalised in the relatively early stages of the search and as a result a large number of solution evaluations are potentially wasted in the later parts of the search. Therefore if pipe diameters of specific pipes can be fixed hence limiting the search space by reducing the number of decisions, then in theory the optimisation will arrive at an acceptable solution using fewer evaluations. By integrating both state of the art optimisation and visualisation methods, WDNet3D hopes to pave the way for greater interaction between algorithm and network in the future.

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