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Estimation of Real-Time Demands on the Basis of Pressure Measurements

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Abstract

The aim of the investigation, reported in this paper, was to estimate real-time demands in a water distribution system (WDS) on the basis of the pressure measurements. The task has been formulated as an optimization procedure which determines water fluxes that minimize differences between measured and modelled pressures. The Levenberg-Marquardt algorithm (LMA) and a genetic algorithm (GA) have been tested to solve the problem. The comparison showed that the LMA works much faster than the GA. The investigation showed also that the higher the demands, the lower is the sensitivity of the results to random errors in pressure measurements. All calculations have been accomplished using measurements executed in an operational WDS for different years and for different weekdays.

Keywords: real-time demands, water distribution system, optimization, Levenberg-Marquardt algorithm, genetic algorithm.

1 Introduction

Computer models of water distribution systems (WDS) contain information on demands. Usually these demands are obtained on the basis of typical hourly values for different type of consumers and on information on month consumption of water. Experience in calibration of WDS models shows large uncertainties of hourly demands estimated in such a manner. Demands are usually measured for quite long periods of time (e.g. month) and give information only on the average base demand. The typical dynamics (patterns) of demands, which are used for the lack of more detailed information, may differ from real demands in time (e.g. during different weekdays) and in space (e.g. because of different daily plans of the residents of different parts of the region). Large differences between typical and real-time demands have been indicated in [1, 2]. At present, researchers study mostly the differences in demand patterns on different weekdays, in different seasons and in different district meter areas (DMA) or investigate the probabilistic nature of demand [3]. The influence of the effects of population age, the share of wells, housing patterns, precipitation and temperature has been also investigated [4, 5]. Special attention is paid to the location of leakages inside WDS on the basis of modelling [6], but location of leakages, using a WDS modelling, needs in addition quite good data on demand fluxes. Investigations of the spatial allocation of total demand are rare [7]. All these investigations are useful in day-to-day work but they can not help in case of deliberate or accidental chemical or biological threats because demands in such a cases definitely are not typical as lot of customers will stop water consumption after alarm. It will lead to situation when real-time fluxes will differ drastically from any typical fluxes. The software EPANET-RTX (under development), will enable real-time estimation of water demands using real-time hydraulic measurements of pressure and flow rates, however this software will estimate water demands only on the group consumers level for demand zones [8]. The aim of this paper was to test the possibility to find real-time water demands inside of a DMA on the basis of pressure measurements. The topic is especially important in the light of necessity to improve drinking water security management in large cities in EU [9]. This security management needs real-time water fluxes in WDS to estimate propagation rate of the contaminated zones. Differences between typical demands in a WDS model and real-time demands lead to differences in typical and real-time velocities and directions of water flow.

Real-time water demands may be estimated on the basis of real-time measurements of water flow and pressures. The number of water flow measurements is often smaller than the number of pressure measurements. As a result we have areas where only pressures have been measured. Estimation of the real-time demands on the basis of the pressure measurements may be formulated as optimization task which minimize differences between measured and modelled pressures. The investigation proceeds from assumption that pressures are modelled using calibrated WDS model [10, 11].

Special software has been developed for estimation of real-time water demands in a WDS. The software is based on the TOOLKIT developed by Rossman [12] for the EPANET2. Subroutines were developed in Visual Basic and in Visual C++, and MS Excel workbook was used as a container for additional data. First of all the comparison was accomplished to solve the task by different optimization software (LMA and GA). Both these softwares have been developed by Argonne National Laboratory (University of Chicago). Minpack package, which uses LMA algorithm, has been rewritten from Fortran into Visual Basic and into Visual C++. The LMA works only with the appropriate selection of the increment of parameters for the calculation of partial derivatives if the Epanet2 software is used [10] for WDS modelling. Therefore the minpack software was modified to give the user a possibility to test the different minimal steps along the parameters for the calculation of partial derivatives in the LMA. One small modification has been done in pgapack also. Original version uses user function (function to be minimized) inside of pgapack. On the contrary, pgapack software has been used as optimization procedure inside of our software in this case.

All calculations have been accomplished using measurements executed in operational WDS in different years and in different weekdays.

2 Method of calculations

As was mentioned above estimation of real-time demands may be accomplished using the WDS model with roughness of pipes calibrated in some manner. This investigation is based on the model calibrated by the method described in [10, 11, 14, 15]. The estimation of real-time demands is based on the attempt to find the demands in junctions with pressure measurements that minimize errors between the measured and modelled values. The objective function (OF) for this task is formulated as

$$OF = \min \sum_{i=1}^{n} error_i^2 \qquad (1)$$

where

$error_i$ – the difference between the measured and simulated pressures in junction i; n – number of junctions with pressure measured. It must be noted that it is impossible to change water fluxes arbitrarily since the water balance must not be changed (inflow to WDS measured must be equal to sum of demands). It means that if a junction demand is increased by some value, the water balance must be ensured by decrease of demand value/values in other junction/junctions. The description of approach used can be found in more details in [1].

3 Application and discussions

The method proposed has been tested on the measurements accomplished in a part of the WDS of the city of Tallinn in the years 2009 and 2011. This part of the WDS contains more than 2000 pipes and more than 1000 consumers. Water pressures have been measured in 20 points (Figure 1).

3.1 Comparison of LMA and GA algorithms

As was mentioned above LMA and GA algorithms have been compared to solve the task. The fact that both algorithms have been realized in software prepared by the same laboratory (see part 1) ensures the same quality of programming and, consequently, comparability of the results. It must be mentioned once more that LMA algorithm has been modified in the part of calculation of Jacobian [10] because original version practically stays at initial values of parameters. GA uses only one processor at these calculations. Comparison of LMA and GA algorithms have been accomplished to compare the time needed for calculations with different number of parameters and possibility to find global minimum if number of parameters is higher than 10. Number of parameters depends on number of points of measurements that was taken into account for each variant of calculations and it is lower by one than number of points of measurements in our case. Table 1 lists the points of measurements that were taken into account in each variant of calculations.

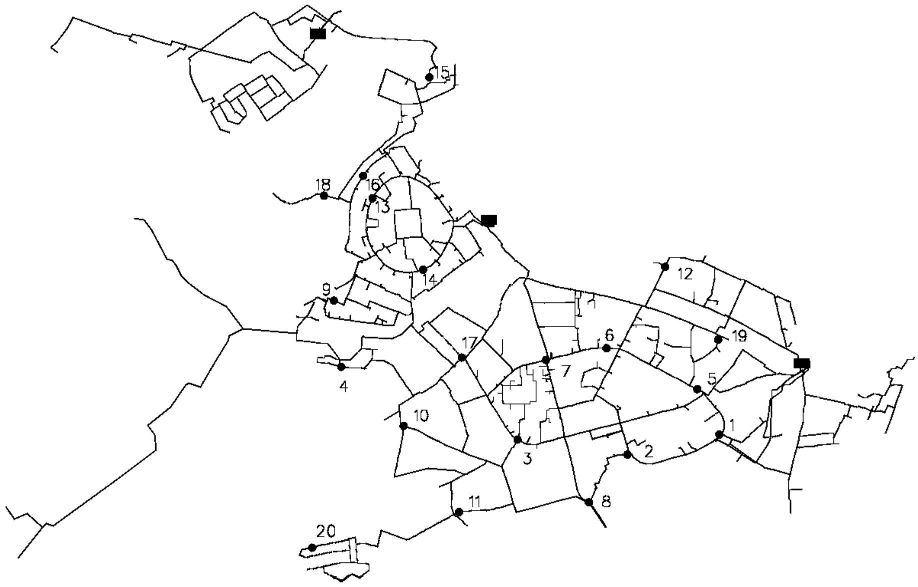

Figure 1. Location of points of pressure measurements in the year 2009. Black rectangles present water sources.

Number of parameters	Number of points of measurements	List of points (see Figure 1)
4	5	1,2,3,4,19,
7	8	1,2,3,4,19,5,6,7
13	14	1,2,3,4,19,5,6,7,8,9,10,11,12,13
19	20	all points

Table 1. List of points of measurements, which were taken into account for different variants of calculations.

Results of calculations are presented in the Table 2.

	GA		LMA	
Number of parameters	Time of calculations in seconds	*OF* (sum of error squares)	Time of calculations in seconds	*OF* (sum of error squares)
4	350	6.01E-04	0.7	6.01E-04
7	2170	2.11E-06	1.4	2.09E-06
13	4080	1.62E-05	3.1	3.80E-09
19	failed to obtain acceptable results		6.6	7.28E-11

Table 2. Results of calculations by LMA and GA with different number of parameters.

One can see from Table 2 that both LMA and GA give the same results if number of parameters is low (e.g. 4 in the Table 1). But even in this case GA works several hundreds times slower. Increase the number of parameters increases the computer time for both algorithms but LMA stays much faster in all variants. Other demerits of GA are that it can not find the same point as LMA if number of parameters is 13 and it was incapable of finding acceptable solution at all if number of parameters was 19. Different population sizes and different iteration numbers have been used in attempt to find solution. And again even if number of parameters was relatively low (7 for example) it was necessary to accomplish several series of calculations to find solution that LMA finds at first attempt. Thus, the results showed that GA is not acceptable to real-time calculations when results must be obtained in reasonable time (in several minutes). Use of multiprocessor calculations does not decrease computer time significantly as multiprocessor approach requires farming algorithm (see definition in [13]) and that means necessity of thousand processors to decrease computer time to value comparable with LMA computer time. The LMA based on minpack with modifications described in [10] works very good and gives results in several seconds with very low sum of error squares (Table 2). LMA has been used in all our further calculations.

3.2 Comparison of results obtained for different weekdays and different years

Series of calculations have been accomplished to investigate stability of the estimated real-time water demands in different days of week and in the same day of week in different years. But first of all calculations have been accomplished to estimate influence of pressure sensor errors on results of calculations.

3.2.1 Influence of the sensor errors on results of calculations.

Sensors for pressure measurements do not measure pressure exactly. According to discussion with personal who did measurements sensors error is ±10 cm. In order to investigate influence of such errors the data disturbed by this error have been used. Investigation showed that 10 cm error in pressure measurement leads to errors in estimated real-time water demands and values of these errors depend on demands in WDS at the moment of measurements. The higher the demands were at the moment of measurements the lower were errors. This dependence is given in Figure 2. One can see that largest errors are at lowest demands (e.g. at night time).

3.2.2 Comparison of results obtained for different weekdays

Investigation has been accomplished to evaluate stability of the real-time water demands estimated on the basis of pressure measurements for different days of week. Results showed that for the most of weekdays real-time water demands were quite stable with relatively small differences from day to day. Figure 3 shows for example dynamics of estimated water demands on Monday and on Wednesday. One can see that in general real-time water demands are lower in middle of day and higher at morning and at evening. Differences may be explained by precision of sensors (error may be about 2 l/s), random fluctuations, and specific behaviour of consumers in different weekdays.

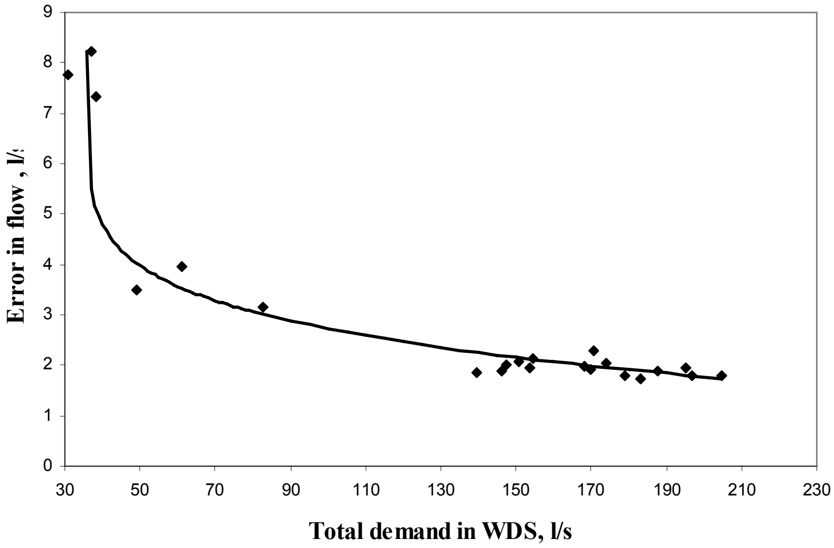

Figure 2. Influence of water demand in WDS on error of the estimation of real-time water demands (pressure error assumed to be 10 cm).

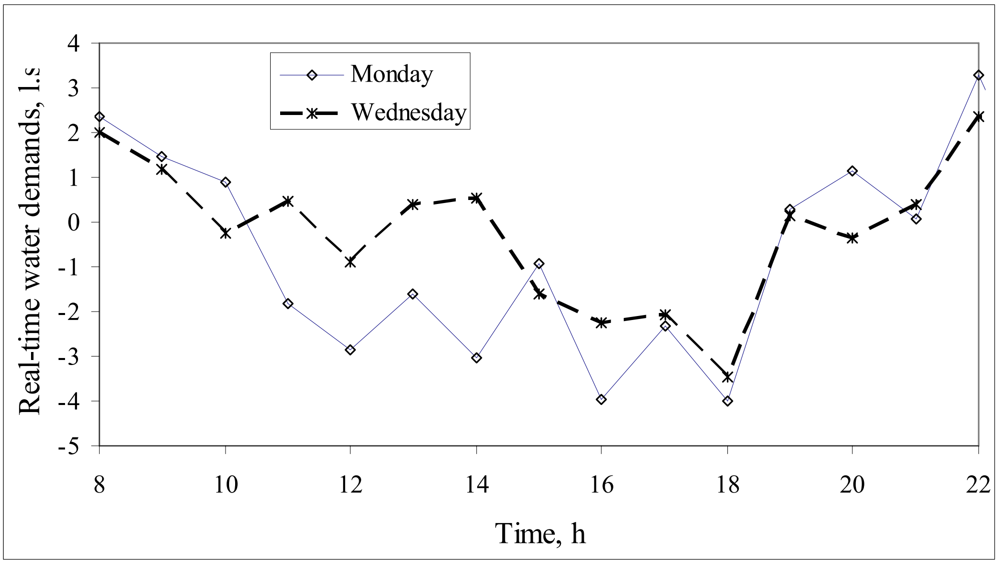

Figure 3. Real-time water demands estimated for Monday and Wednesday in the year 2009 for the point 8 (see location of the point in Figure 1).

3.2.2 Comparison of results obtained for different years

Investigation has been accomplished also to evaluate stability of the real-time water demands estimated on the basis of pressure measurements for the same weekday in different years. Data of measurements accomplished in the years 2009 and 2011 have been used in comparison. Figure 4 represents results obtained for Monday in these two years. Unfortunately locations of points of measurements were different in these years. Therefore only 12 points are presented in Figure 4 with locations that were almost the same in both years. One can see that fluxes mostly are quite similar in both years.

4 Conclusions

The conclusions of this paper are:

- Comparison showed that estimation of real-time water demands is too complex task for a GA if number of parameters is larger than 10. Besides, the GA requires several hundreds times more computer time than LMA. Therefore the use of a GA is problematic to solve this task in real-time calculations of propagation rate of the contaminated zones in case of deliberate or accidental chemical or biological threats when small calculation time is vitally important.
- The LMA works very fast and can be used for this task.
- Estimation of the real-time water demands on the basis of pressure measurements depends on precision of the pressure sensors and on current demands in WDS.
- Calculations for different weekdays and years showed that space and time differences in real-time water demands in ordinary situations contain both typical and random constituents.

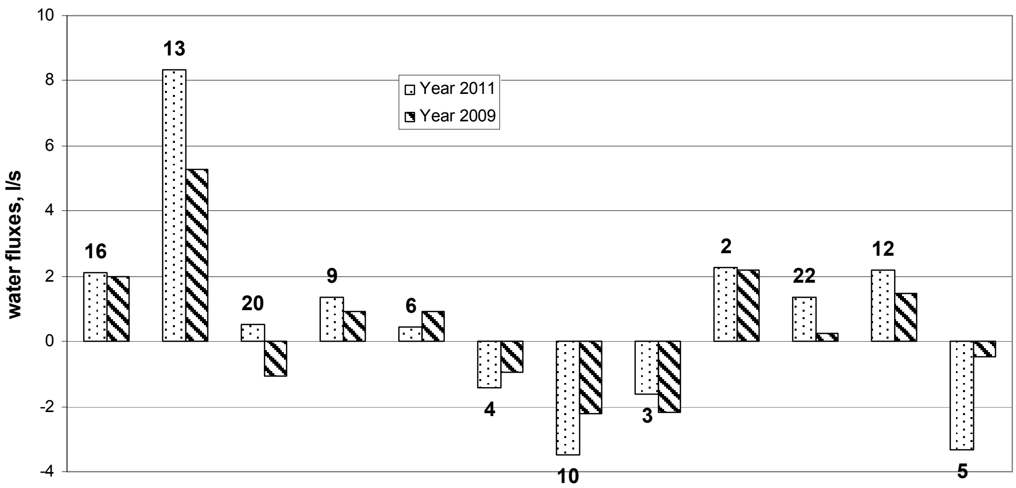

Figure 4. Water fluxes estimated for Monday at 20 o'clock in the years 2009 and 2011 (number in Figure correspond to numbers in Figure 1)

Acknowledgements

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