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Zastosowanie systemów monitoringu w systemach wspomagania decyzji

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Raport

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Pod redakcją Jana Studzińskiego i Lucyny Bogdan

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Raport zawiera 3 nieopublikowane artykuły omawiające zastosowania systemów monitoringu w systemach wspomagania decyzji. Pierwszy z artykułów będzie przedstawiony na konferencji pn. Quality, Reliability, Maintenance, która odbędzie w dniach 1 – 2 kwietnia 2004 w Oxfordzie. Dwa pozostałe artykuły ukażą się w publikacji książkowej IBS PAN w serii Badania Systemowe w 2004 r.

Spis treści

Artykuły:

Problems of Computer Aided Decision Support System for a Municipal Water Network

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Abstract: *In the paper some results of the development of a computer aided decision support system for the operator of a municipal water network are presented. The system consists of three cooperating modules: the numerical map of the water network, the monitoring system and the computer program for hydraulic calculations and for optimisation. The numerical map is based on a GIS system adapted for the needs of the water network. The modules of computer system cooperate each other using the Branch Data Base, which comprises the information about the water network structure and about its elements necessary to carry out the tasks of the modules such as visualisation, data processing and hydraulic calculations.*

1. Introduction

The system under consideration was created for the municipal water net in the polish city Rzeszow, which owns 160 000 inhabitants. The length of the municipal net is 544 km (the water mains 49 km, the distribution network 274 km and the user attachments 221 km). In the water network there are five surge tanks with capacities 1 x 3.600 m^3 and 4 x 3.000 m^3 and there are 21 pumping stations. The network is supplied from two water intakes form the river with their efficiencies of 37.000 m^3/day and 47.500 m^3/day. There are 12.201 group consumers in the network and 80% of the net works in the ring system. The main receivers of the water are the households. The amount of damages is about 500 damages/year and the damages are caused mainly by the age and age differences of the pipe material.

2. The creation of the numerical map

To work out the numerical map of the municipal water network a specialised program for creating numerical maps (GIS) was gained. The map of the water network was done on the base of vectorized geodetic maps of the town. System GEOMEDIA by *Intergraph* was bough and then adapted for the needs of the water work. Such the way of work enables to be independent from the external computer firms in the future. But the adaptation of a standard GIS causes the necessity of solving the following three tasks:

1. To define the structure of the object data basis applied by GEOMEDIA system for visualisation of the water network and for description of its parameters.
2. To define and implement the special user functions to enable the numerical map to work as a tool to manage the water network.
3. To develop a new organizing structure in the plant to enable the fast working out the numerical map and the permanent correction of it.

The numerical map consists of a scheme of the water network and of describing database attached. To enable the map to represent the real water network all characteristic network elements must be distinguished on the scheme and respectively all parameters of these elements, called attributes, must be set in the database. During the work out of the numerical map the database structure must be defined. It means that the objects of the database and their attributes must be designated. After a detailed analysis of needs of the municipal water network in Rzeszow has been done the branch database for the water net was worked out.

The special functions enable to apply the numerical map to solve the tasks realized during the exploitation of the water network. The following special functions were defined:

- Updating of the numerical map
- Geometric and describing data export/import from/to numerical map
- Identification of conflicts between different branch nets
- Disconnecting of a part of water network in case of the damage
- Printing of exploitation and damage reports.

The analysis of exploitation conditions in the plant indicates that the optimal solution for the firm using the numerical map is to create a separate numerical map laboratory. In such the place a group of people could be able to make the computer program works correctly, the current updating of the numerical map works properly as well as the task of exploitation of the water network going on rightly. Such an organizing structure was introduced in Rzeszow.

3. The creation of the Branch Data Base for the waterworks

The visualisation of the water network on the computer screen is done by application of the water network computer map – GIS. The format of the Branch Data Base and the tools programs realizing the special functions are created on the base of the standard application GEOMEDIA. The functions are connected with the water-supply needs, with the way of receiving the data for creating the numerical map and with the demands of external computer programs cooperating with the numerical map.

The creation of the Branch Data Base Format consists on defining the water network objects and their attributes. The main objects of the water works are: water pipes, pumping stations, tanks, user attachments, shutters, reducers and check-valves and their attributes are lengths and diameters of pipes, characteristics of pumps, geometric dimensions of tanks, the operating conditions and characteristics of shutters, reducers and check-valves. The Branch Data Base (BDB) is the base of working of all computers programs of the computer system.

The data for numerical map are delivered from the geodesy department as DGN files done on the base of the municipal geodetic maps of Rzeszow, which are made in the scale 1:500. That is why the tool program enabling reading DGN files, copying the graphic and description data as well as computer visualisation of the Branch Data Base had to be written for the GEOMEDIA program.. The additional program is used for data updating, i.e. for signalling and introducing to the Branch Data Base the changes done by geodesy department in the DGN files, which were previously introduced to the BDB.

The described Branch Data Base is an application enabling the visualisation of the water network in a form of numerical map. But the Branch Data Base does not enable the cooperation of the numerical map with the external applications, namely with monitoring system and hydraulic model, because the BDB does not include the specific objects used by these applications. Such objects are the nodes of the water network, which do not occur on the geodetic maps. That is why the next step during the creation of the Branch Data Base Format was defining the nodes and nodes attributes. The main nodes in the water network are sources, receivers, montage nodes and measurement nodes. Their main attributes are pressure and water distributions. The numerical map of the water network created directly on the base of the vectorized geodesic maps does not include the nodes and it is topologically incorrect, i.e. it is not continuous and not coherent. That is why the hydraulic calculations cannot be realized on the base of it. To enable it two new programs for topologisation of the water net and for generating the hydraulic nodes (nodes generator) were added to GEOMEDIA besides the mentioned previously programs for reading DGN files and for data updating.

This way the development and implementation of all additional programs mentioned made from GEOMEDIA the right waterworks application for generating the water net numerical map. It should be noticed that as a result three layers of numerical map are generated:

- *the geodesic main layer* created from DGN files delivered directly from municipal geodesy department
- *the topological geodesic layer* created from *the geodesic main layer* after checking and improving the continuity and cohesion of the water network
- *the hydraulic layer* created from *the topological geodesic layer* after introducing the nodes, creating in such a way a new net graph which may be the base of the hydraulic calculations.

4. Problems of mathematical modelling and simulation of the water network

The modelling of the water network consists of the following steps: the creation of the hydraulic model respectively to the investigated water network, obtaining the data describing the investigated water network and performing the simulation calculations and their verification on the base of the measurements.

The water network system is described using linear and non-linear algebraic equations. The number of these equations inereases according to network dimensions and for typical town networks may amount from several hundreds to several thousands. The numerical solution of such great non-linear equations sets is troublesome. The water network consists of the nodes and of the connecting pipes. The nodes may be active and passive. In the network structure usually several circuits occur called eyelets. The mathematical network model consists of the equations describing the water flows in pipes and the pressures in the nodes. To calculate the network means to determine these flows and pressures whereby in the network constituting the eyelets the number of pipes(r) is greater than the number of nodes (w), i.e. $r=w+o+1$, where o is the number of eyelets. That results that the number of unknown values in the network models is $n=w+r=2w+o-1w$.

The model equations arise from the I and II Kirchoff's laws known from electrotechnics and from the Bernoulli's equation known from mechanics of fluids. From the I Kirchoff's law used for the network nodes we can get the set of w linear equations for r flows. From the II Kirchoff's law used to the eyelets we can get the non-linear equations for flows and from Bernoulli's law we can get the set of ($w-1$) equations which are linear with regard to pressures and non-linear with regard to flows. By solving the equations we will find the flows and water pressures in the network. The calculation of the model is more difficult than its formulation because of many equations and because of their non-linearity. Generally the four methods of calculating the water networks are possible:

- Direct solution of the set of n both linear and non-linear equations regarded as a non-linear set for simultaneous determining of all flows and pressures

- Separate calculation of flows and of pressures; the flows are calculated from the set of $(w+o)$ linear and non-linear equations obtained from Kirchoff's law and the pressures are calculated from the set of $(w-1)$ linear equations obtained from Bernoulli's equation
- Separate calculation of flows and pressures; the flows are calculated iterative by turns from two equation sets – linear (from the I Kirchhhoff's law) and non-linear (from the II Kirchohoff's law) – and the pressures are calculated as previously from the linear Bernoulli's equations
- Separate calculation of flows and pressures from the three as above equations sets; the flows are calculated from two sets of equations, linear and non-linear, solved independently.

In the first, second and third methods the Newton's algorithm may be used to solve the non-linear equations and the Choleskys's algorithm for linear equations. In the third method the relaxation algorithm is used as the iterative one for alternative solution of the flow equations. The above methods are known, checked and infallible but using the Newton's method for solving the non-linear equations and the relaxation method for flows calculations takes time. This is the meaningful disadvantage especially in identification and optimisation problems because the calculations are repeated many times. The forth method concerns in using the specialised approach (Cross', Lobaczewski's and Andrjaszew's), which was worked out only for water network calculations. These methods consist in general in dividing the starting problem in three smaller and independent problems and in solving the non-linear equations set for flows using the specialised fast iterative algorithm. In our case the Cross' algorithm was used.
The own modelling program was implemented. This program uses the Cross method for solving the non-linear algebraic equations built for the water network rings. It takes into account such the objects as water works pipes, water works pipes with section distribution, water works pipes with shutters, reducers or valves, supplying nodes in the form of pumping stations or tanks, montage nodes, measurements nodes, receiving nodes in the form of tanks or being user attachments on the geodesic map, and the nodes increasing the pressure in the form of water supplies. The program is written in DELPHI. It has an extended interface and its own graphical editor what enables to perform the calculations and creating the water network graph on the computer screen independently on the numerical map.

The program data concerning the water network structure and its parameters are delivered from the numerical map using some buffer files. The buffer files concerning pipes and hydraulic nodes are generated basing on the numerical map hydraulic layer. The modelling program worked out has the possibility of using the nodes and section water distributions. This program can also execute the statistical calculations on the base of given average day or moment water distributions and can execute dynamical calculations basing on the given day hour distribution sequences. The verification of the hydraulic calculation results is performed as a comparison between the program results and the monitoring system measurements.

5. The correctness of the model

The simulation calculations were performed for the chosen part of the town water network using the mentioned modelling program. The monitoring system was installed for this part of the water network. For this part of the water net the numerical map has been created and the data could be delivered using the Branch Base Data. The chosen part of the net comprised one quarter of the town and it was about 10% of the whole municipal water network. The results obtained from the model were compared with the measurements got from the monitoring system. The comparison analysis showed the correctness of the proposed model.

6. Optimisation algorithm of water network and control algorithm in break-down states

An optimisation algorithm, which is an integral part of the modelling program, was created. It is a specialized algorithm using the specificity of the water network. The optimisation task concerns improving the pressures in the water network nodes in the case of exceeding the given pressure limit values. In the classical optimisation method the object function is based on the difference between the given pressure value and the calculated pressure value and this function is minimised depending on the water network pipes diameter values. The object function is the mean square criterion and the change of parameters takes place in the whole net what increases the calculation time in the case of large nets.

In our algorithm firstly the paths with the greatest flow resistance between supply sources and the nodes with not appropriate pressure are marked in the graph. Then the distance between the given pressure and calculated pressure in these nodes is minimised depending on the change of water network pipes diameter values only on marked paths. Such a procedure shortens the calculation time because it deals in calculations with only the marked parts of the net. The break-down algorithm concerning situations when the break-down has place in some points of the net was performed. In such a case the proper part of the water network should be cut to avoid a loss of water. The algorithm realizes this task by indicating the closest gate valves which should be closed to cut the water flow. The algorithm works on the numerical map hydraulic layer level. The new water network graph with the cut part of the break-down is received as the result of the algorithm. The hydraulic calculations for obtaining flows and pressures may be now performed on the base of this new graph.

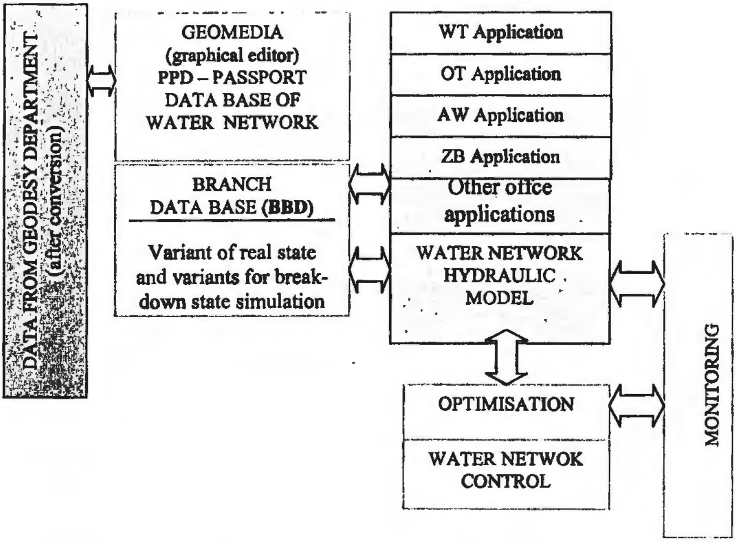
7. The computer system for the operator decision support

The computer system consists of three modules performing the functions of numerical map, monitoring system and hydraulic model with optimisation algorithm. To start the monitoring system the measurements points were given as the results of hydraulic calculations in the investigated part of the water net work. The investigated area consists of 2 pressure zones separated by water supply system. There were indicated 9 measurement points, i.e. 2 water network supply points, 2 water output points (from the investigated area to not investigated net areas), 2 measurement points in the first pressure zone in the place of minimal and maximal pressure, 2 measurement points in the second pressure zone in the place of minimal and maximal pressure, and I measurement point in the water supply system separating two pressure zones.

The water flows and the pressure are measured in the points of water inflow and outflow as well as in the water supply system. Only the pressures are measured in the rest measuring points. PROCON system based on the original German system using the controllers by SIEMENS was bought to perform the monitoring system.

The measurement transmission system from measurement points to the computer with the PROCON program installed is based on the GSM system. The system works in the computer net consisting of tree computers.

The computer system scheme [4]



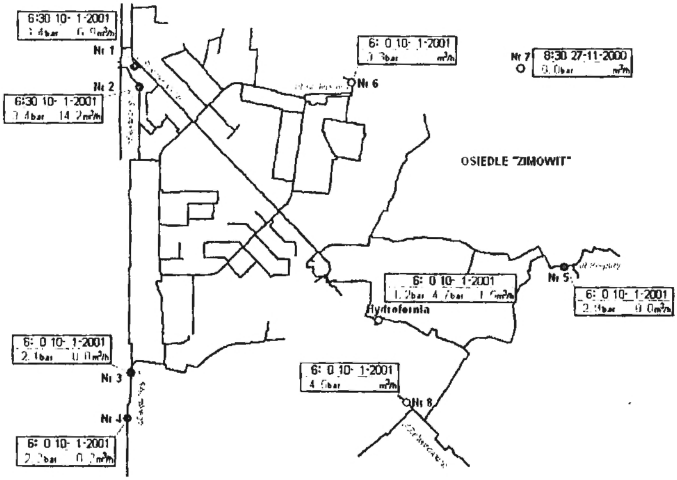
During testing the tool programs connected with numerical map and enabling the cooperation among the numerical map, the hydraulic model and the monitoring system, it appeared that the additional program modules performing managing functions and some other functions, would be useful. There are the following additional preferable modules (applications):

- WT Application –program for technological conditions maintenance
- OT Application – program for technical receivers, which cooperates with WT Application
- AW Application – program for break-down maintenance and water network inspection maintenance
- ZB Application – program for water sewage disposal maintenance
- Other Application – office software.

The presented computer system consists of seven computers in which three computers cooperate with numerical map, two computers are used for monitoring system maintenance and the last two computers are used for the maintenance of hydraulic model and optimisation program. The data transmission is done using the GSM system. It is an innovation solution in the water networks monitoring systems. It secures the transmission reliability but unfortunately it is not cheap. It is why the economical scheme of measurement data transmission was worked-out. In this scheme if the measured flows and pressures do not exceed some given limit values the transmission takes place only in some chosen time moments. There are now the following hours of transmission: 6:00, 14:00 and 22:00.

In the case when the limit values are exceed or for the operator demand the alarm mode transmission may start any moment. In such a way the transmission costs are minimal if the water network works in regular mode.

The measurement points scheme in monitoring system [4]



8. Remarks

The presented system is an original system developed for one municipal water network and it uses the possibilities of integrated systems for computer aided decision making. Numerical maps, hydraulic models and monitoring systems work autonomously in some Polish water networks usually as independent programs and the possibilities of cooperation of this programs in one system are unfortunately not used.

9. References

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