Non-linear Pipe Networks Water Management Real-Time Expert Telematics System

E. G. Ladopoulos

Interpaper Research Organization, 8, Dimaki Str. 106 72 Athens, Greece

eladopoulos@interpaper.org

Abstract- **A non-linear real-time expert water management telematics system is proposed, in order to minimize the waste of 15% to 40% of the water supplies in the ground pipe networks, because of the leakage. Such an expert telematics system will work by using the step testing method, in order to be possible to determine the approximate location of leakage for every big urban area. Moreover, in order to handle data in the Workstation of the Central Station (CS) the ARC / INFO Geographic Information Systems (GIS) is used, working under the UNIX-operating system in X-Windows. The proposed real - time expert system will be non-linear in its responses and a part of the programming language will be fourth generation real-time software working under real-time logic.**

Keywords- Non-linear Real-Time Expert System; Telematics System; Real-Time Logic; Water Management System; Geographic Information Systems (GIS); Leaks Control; UNIX - Operating System; Centrally Controlled System

I. INTRODUCTION

Water distribution networks form essential components in any urban development. They require major capital investment and carry with them substantial liabilities for many years to come in respect of operation, maintenance and repair. In many countries all over the world, water pipe networks are well over 60 years old. The distribution system comprises of pipes of different materials, which are usually cast iron, ductile iron, asbestos-cement, steel or PVC. Because of the oldness of the pipes, leakages are produced. Also, the original causes of leakages in the pipe networks are the following:

- earth movements, road works and trench works in the vicinity of the pipeline;
- poor bedding conditions and shallow depths of cover;
- water hammers;
- bed assembly;
- water aggressiveness and soil corrosivity due to adopted protections;
- manufacturing faults.

Consequently, it is necessary to determine the approximate location of leakage within the high loss area. The precise locating of the leak position combines a comprehensive range of modern technologies with high technical operator skills.

Water demand is related to population and the raised expectations accompanying economic growth, while supply is matter of climate, run-off, ground storage and engineering. At the start of 2000 's it was estimated that one and a quarter billion people in developing countries were without access to adequate and safe drinking water supplies and one and three quarter billion without proper sanitation.

In industrial countries until recently, water supply was not the subject of much public attention or interest. However, several facts have led to a change during the last few years and today the problem has very much increased. Also, in these countries new sources of water resources are even more difficult and expensive to be determined. Another factor which is brought to main concern is the water management and especially the privativation of water industry. Many questions have been raised about the water price in many industrial countries.

In order therefore the growing expenses, because of the increase of the water price, to be balanced, sustained efforts will have to be supported in order to reduce the produced quantity of water. Among the main factors, leakage may be considered as the most important source of expense. In general the water experts think that the amount of leakage is between 15% and 40% of the water supplies. Thus, in order to successfully control the fluid losses from a pressurised pipework system, it is required a sophisticated planned investigatory program combined with an ongoing monitoring exercise executed by experienced and well trained staff.

The unsteady flow was extensively studied by E.G. Ladopoulos [1] and the non - linear methods [2], [3] used for solid mechanics applications were extended to the solution of two-dimensional flowfields [4] - [7]. Moreover, E.G. Ladopoulos and V.A. Zisis [8] - [10] introduced non- linear singular integral equation methods for studying two- dimensional fluid mechanics applications.

Also, real-time expert systems were studied by A.K. Agrawala and S.T. Levi [11], [12]. Centrally controlled systems were further investigated by R.Gusella and S. Zatti [13], [14], W. Gora, U. Herzog and S. Tripathi [15], S. Tripathi and S. Chang [16], and D.L.Mills [17]. Distributed controlled systems were introduced by L. Lamport [18], [19], L. Lamport and P.M. Mellier-Smith [20], J. Lundelius and N. Lauch [21], K. Marzullo and S. Owicki [22] and K. Shin and P. Ramanathan [23]. F. Jahanian and A. Mock [24], [25] further studied Real - time logic systems.

The principle of intelligent modelling was introduced with the purpose of system control, which incorporates every type of modelling techniques, like quantitative, qualitative or rule - based techniques. Such intelligent modelling was investigated by M. Jamshidi [26], J. Dekleer and J. S. Brown [27], B. Kulpers [28] and J.A. Ress and W. Clinger [29]. Also, there are some special software tools for the implementation of real-time expert systems and such real-time programming languages were investigated by scientists like R. Emnis et al. [30], W. Fritz, V. H. Haase and R. Kalcher [31], and V. H. Haase [32].

Our present investigation is therefore referred to the design of a non-linear real - time expert water management telematics system in order to minimize the waste of 15% to 40% of the water supplies in the pipe networks because of the leakage. Such an expert system will be a Centrally Controlled System (CCS) with several Local Stations (LS), composing of wired as well as wirelesses connections by using a microwave network. The programming language will be fourth generation real - time software.

II. STEP TESTING METHOD FOR LEAKS CONTROL

The step testing method is established as the most effective means of locating waste water. According to this technique the water distribution system is divided into waste zones: (Fig. 1)

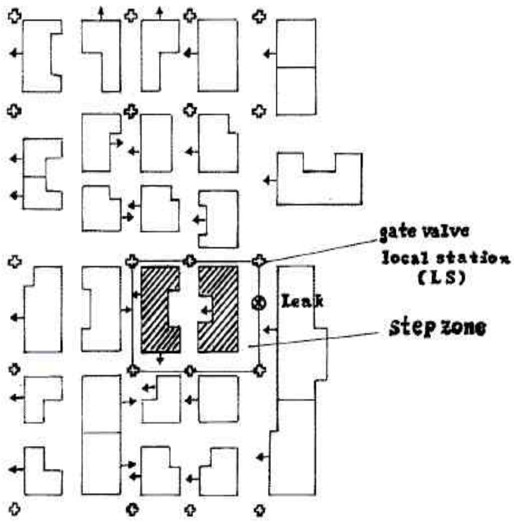

Fig. 1 Waste Zones for Step Testing

All the gate valves of the pipe networks are composing the Local Stations (LS) of the proposed Real-Time Expert System. These are connected with the Central Station (CS) by wired or wirelesses connections, in order to open or close automatically. Also, in every gate valve (or local station - LS) will be included a flowmeter in order to measure the value of flow in m^3/sec.

During the night, the gate valves will be closed automatically for very small intervals (5 to 15 seconds), shutting off streets for this small period. Now, all the water consumed in the step zone is being measured without any interruption in supply. Also, through the flow meter which is included in the gate valve the flow data are measured in m3/sec.

The recorded consumption curve shows therefore the principle of occasional zero consumption. If there is a leak the curve does not drop to an occasional zero, but repeatedly to the same minimum. (Fig. 2 , 10 m^3/sec)

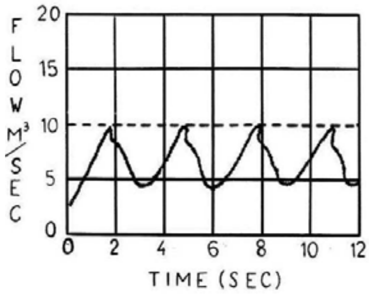

Fig. 2 Flow Diagram, when a leak exists and therefore the curve doesn't drop to zero, but repeatedly to the same minimum

Thus, by the proposed Real-Time Expert System applied to the Step Testing, it is possible to determine the approximate location of leakage for every big urban area. Then the exact location of the leakage is easily determined by geophone or correlator.

Also, the size of the step zone is chosen according to the position of the gate valves, the number of consumers and their consumption habits.

The Central Station of the proposed Non - linear Real - Time Expert System includes a SCADA server (a workstation responsible for scanning remote sites and storing the real - time data) on a hot-stand with an operator workstation, both running under UNIX operating system, a laser - printer, two modems, one line sharing device and a system of uninterrupted power supply (UPS) capable for 6 to 8 hours back up. (Fig. 3)

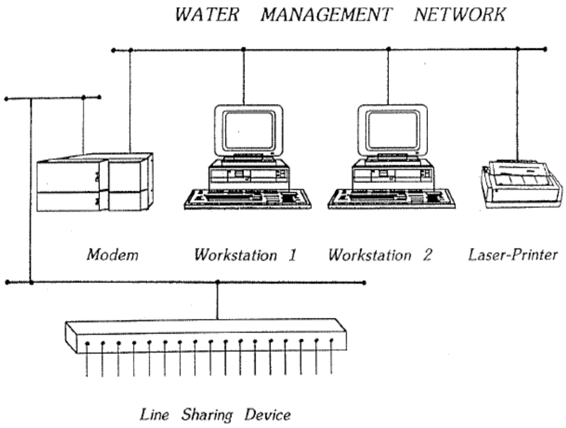

Fig. 3 Schematic Diagram of the Non-linear Expert Water Management Telematics System

Geographic Information Systems (GIS) working under the UNIX-operating system are used in the Workstations 1 and 2 in order to handle data. By using the ARC/INFO G.I.S, the typical directories include land cover, soils imagery, topography and water information. In general the GIS is defined as a system of capturing, storing, manipulating, analyzing and displaying spatial information in an efficient manner. It is a software package that efficiently relates graphical information to attribute data stored in a database and vice versa.

The GIS supported by computer graphics, provide powerful means in which the graphical information, attributes and textual information can be stored, retrieved and used by matching with other parts of the integrated information system.

Furthermore, the adoption of X - Windows in expert systems has very much changed the format, quantity and sources of information presented to the operator of the expert system. X-Windows software permits display of multiple screens on a single screen so that, for example, real -time and historical data can be viewed at the same time. The integrated real - time expert system is using this split- screen capability, known as windowing, in order to reduce the number of space needed and enable the control-room operator to simultaneously view the GIS maps, work orders and customer information.

The Central Station of the proposed Non-linear Real- Time Expert System includes also a wall Mimic Diagram which displays information about the status of the various communication links with the Local Stations (LS) which are the gate valves of the pipe network of the urban area under study.

III. CENTRALLY CONTROLLED SYSTEMS

The proposed non-linear real-time expert system is a centrally controlled system. Let a central station i begin a synchronization produce, at a time T_1. Hence, the current value is C_i (T_1) with an error e_1 and sends this value to a local station (LS). The message travels for μ_i^j time units, and is received by the local station at T_2.

At this time the local station has the value C_j (T_2} with an error e_2. The local station can now compute the difference:

$$d_1 = C_j(T_2) - C_i(T_1) \tag{3.1}$$

Furthermore, by comparing the receiving time and the sending time:

$$C_i(T_1) + e_1 + \mu_i^j = C_j(T_2) + e_2 \tag{3.2}$$

finally follows:

$$C_j(T_2) - C_i(T_1) = \mu_i^j + (e_1 - e_2) \tag{3.3}$$

Also, if we model the error difference such that ξ_j is the j skew and E_j^k (k=1,2,…….) is a noise, then we obtain:

$$d_i = \mu_i^j + \xi_j - E_j^1 \tag{3.4}$$

Then, we repeat the process in the opposite direction. The local station reads its current value at a time T_3, $C_j(T_3)$, with an error e_3. It sends this value to the central station, attaching d_1 to it. The message travels for μ_j^i time units and the central station receives it at T_4. At that time, the central station has the value of $C_i(T_4)$ and an error e_4. The central station can now compute the difference:

$$d_2 = C_i(T_4) - C_j(T_3) \tag{3.5}$$

By comparing the receiving time and the sending time:

$$C_j(T_3) + e_3 + \mu_j^i = C_i(T_4) + e_4 \tag{3.6}$$

from which follows:

$$C_i(T_4) - C_j(T_3) = \mu_j^i - (e_4 - e_3) \tag{3.7}$$

and as in the previous case:

$$d_2 = \mu_j^i - \xi_j - E_j^2 \tag{3.8}$$

From eqs (3.4) and (3.8) we obtain:

$$\frac{d_1 - d_2}{2} = \xi_j + 1/2(\mu_i^j - \mu_j^i) - 1/2(E_j^1 - E_j^2) \tag{3.9}$$

Thus, we can use the subtraction of d_2 and d_1 in order to estimate ξ_j and the correct $C_j(T_3)$.

IV. THE PROPOSED UNIX OPERATING SYSTEM FOR THE CENTRAL STATION

The proposed Unix Operating System is analogous to the distributed Berkeley Unix [13], [14]. The Central Station node in this Operating System obeys three results:

- The first is the initiation rule, in which the Central Station sends its current value to the Local Station.
- In the second rule, the final reception rule, the Central Station receives from a Local Station j a message that contains the difference d_1^j and the transmission time of this message, T_B. Upon reception, the Central Station calculates the second difference, d_j^2.
- The third rule is the correction rule. After N polls for the Local Station j, the Central Station calculates the average skew found in these polls, Δ, and sends it to j.

The three rules are given as following:

- Upon Initiation of Skew Measurement:

Do

$$T_A \leftarrow C_i \text{ (now\}}$$

$$\forall j \neq i: \; Send\ (T_A)\ to\ j$$

endo

- Upon Receiving (T_B, d_1^j) from Local Station j:

Do

$$d_2^j \leftarrow C_i\ (now) - T_B$$

$$\left|* \ d_2^j = \mu_j^i - \xi_j - E_j^2 \ *\right|$$

$$\Delta_j \leftarrow 1/2(d_1^j + d_2^j)$$

$$\left|* = \xi_j + 1/2(\mu_j^i + \mu_i^j) - 1/2(E_j^1 - E_j^2) *\right|$$

endo

- $\forall \ j \neq i:$ Upon Complete Receiving All Polls:

Do

$$\Delta \leftarrow 1/N \sum_{k=1}^{N} \Delta_j(k)$$

$$\left|* = \overline{\xi}_j + 1/2(\overline{\mu}_i^j - \overline{\mu}_j^i) - 1/2(\overline{E}_j^1 - \overline{E}_j^2) *\right|$$

Send (Δ) to j

endo

V. THE PROPOSED UNIX OPERATING SYSTEM FOR THE LOCAL STATION PJ

According to the proposed Unix Operating System each local station node obeys two rules:

- The first rule is the reception of an initialization message from the Central Station. When such a message arrives, the local station *j* calculates the difference d_1^j. Then, sends the calculated difference and T_B to the central station.
- The second rule of the Local Station is the value update, as dictated by the Central Station correction.

Thus, the two rules are given as following:

- Upon receiving (T_A), from the Central Station *i*:

Do

$$d_1^j \leftarrow C_j \ (now) - T_A$$

$$\left|* \ d_1^j = \mu_i^j + \xi_j - E_j^1 \ *\right|$$

$$T_B \leftarrow C_j \ (now)$$

Send (T_B, d_j^1) *to i*

endo

- Upon receiving (*Δ*) from the Central Station:

Do

$$C_i(t) \leftarrow C_i(t) + \Delta$$

endo

VI. REAL TIME LOGIC FOR THE PROPOSED EXPERT SYSTEM

Real-time logic (RTL) is a reasoning system for real-time properties of the expert systems. RTL's computational model consists of events, actions, causality relations and timing constraints. The model is expressed in a first order logic, describing the system properties as well as the system's dependency on external events.

Moreover, Real-Time Logic uses three types of constraints:

a. Action constants may be primitive or composite. In a composite constant, precedence is imposed by the event-action model using sequential or parallel relations between actions.

b. Event constants are divided into three cases. Start/stop events describe the initiation/termination of an action or subaction. Transition events are those which make a change in state attributes. This means, that a transition event changes an assertion about the state of the real-time system or its environment. The third class, which is the external events, includes those that can be influenced by the system behavior, but cannot be caused by the system.

c. Integers assigned by the accurance function provide time values, and also denote the number of an event occurance in a sequence.

Furthermore, the Real - Time Logic System introduces time to the first order logic formulas with an event occurance function denoted by e. The mechanism to achieve a timing property of a system is the deduction resolution.

We consider the following example: Upon pressing button ≠ 1, action TEST is extended within 60 time units. Dusting each execution of this action, the information is sampled and subsequently transmitted to the display panel. Also, the computation time of action TEST is 30 time units.

This example can be further translated into the following two formulas:

$$\forall\ x : e(\Omega \ \text{button}\ 1,\ x) \le e(\uparrow \text{TEST},\ x) \ \wedge$$

$$e(\downarrow \text{TEST},\ x) \le e(\Omega \ \text{button}\ 1,\ x) + 60$$

$$\forall\ y : e(\uparrow \text{TEST},\ y) + 30 \le e(\downarrow \text{TEST},\ y)$$

VII. ARTIFICIAL INTELLIGENCE FOR THE EXPERT SYSTEM

The conventional mode of describing the behavior of a physical object is the construction of quantitative models. A very important type of knowledge is the so-called "rule based" knowledge. The rule-base associated with any physical object contains production rules of the form:

If < condition on assertions > then < fact >

The rules in classical rule based expert systems are expressed on the basis of assertions, which are objects holding true or false values.

Furthermore, a slight modification of the form of rules makes them suitable to describe deeper knowledge of an expert - system. The new form of the rules is:

If < an expression to be evaluated true or false >

then < fact or action >

In general in realization is used the Scheme programming language, which contains an object - oriented programming extension. The structure of the system to be modelled is realized using the notion of "object ". In the object - oriented programming environment the objects can be defined as instances of classes. The class definition contains definitions of instance variables, a specification of variable treatment, and an enumeration of component classes.

Also, the rules associated with any given object can be represented as the value of the standard instance - variable RULES. One piece of rules has the following form:

(rule - label " if " - expression

" then " - expression)

A finite set of such items can be represented as the association - list:

((rule - 1 if - expression then - expression)

(rule - 2 if - expression then - expression }

……………………………………………

(rule - n if - expression then - expression }

which can be assigned to the RULES variable as a value.

VIII. CONCLUSIONS

By the present research a non-linear real-time expert water management telematics system has been proposed, for the minimization of the waste ranging between 15% and 40% of the water supplies in the ground pipe networks, because of the leakage. Such an expert system will be a Centrally Controlled System with several Local Stations (LS) which are the gate valves of the pipes. This telematics system will work by the step testing method and according to this method during the night, the gate valves will be closed automatically for small periods of 5 to 15 sec. If there will be a leak, then the curve of the flow meter will not drop to an occasional zero but repeatedly to the same minimum. By the proposed real-time expert water management telematics system is possible to determine the approximate location of leakage for every big urban area.

Besides them, in order to handle data in the Workstation of the Central Station (CS), the ARC/INFO Geographic Information Systems (GIS) will be used working under the UNIX-operating system in X-Windows. The proposed real - time expert system will be non - linear in its responses and a part of the programming language will be fourth generation real - time software working under real-time logic.

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Evangelos G. Ladopoulos

Professor Dr. Civil Engineer & Mechanical Engineer.

Included in the list of 2000 Outstanding Scientists of the 20th Century by Cambridge.

Included in the list of 2000 Outstanding Scientists of the 21th Century by Cambridge.

Included in the list of 100 Top Scientists of 2007 by Cambridge.

Over 100 publications in high quality scientific journals.

Project Manager of over 500 Projects in Civil Engineering, Mechanical Engineering and Petroleum Engineering.

Chairman and Professor of Interpaper Research Organization.

Visiting Professor in Universities in Europe and USA.