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Software Determination of Non-linear Water Management Expert System

E.G. Ladopoulos
Interpaper Research Organization
8, Dimaki Str.
Athens, GR - 106 72, Greece
eladopoulos@interpaper.org

Abstract
By the current investigation a modern non-linear real-time expert water management telematics system is further improved and studied, in order to minimize the waste of 15 % to 40 % of the water supplies in the ground pipe networks, because of the leakage. Hence, the step testing method will be used for the design of such an expert system, and so it will become possible the determination of the approximate location of leakage for every big urban area of pipe networks all over the world. Furthermore, ARCMAP Geographic Information Systems (GIS) working under the UNIX-operating system in X-Windows are used in the Workstation of the Central Station (CS) in order to handle data. Besides, 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.

Key Word and Phrases
Water Management Telematics System, Real - Time Expert System, Real - Time Logic, Leaks Control, UNIX - Operating System, ARCMAP Geographic Information Systems (GIS).

1. Water Management

Over the 20th century the world's population tripled, but the use of renewable water resources has grown six-fold. Besides, as it is expected within the next fifty years, the world population will increase by another 40 to 50 %. The above population growth - coupled with industrialization and urbanization - will result in an increasing demand for water and will have serious consequences on the environment.

Also, already there is more waste water generated and dispersed today than at any other time in the history of the earth, more than one out of six people lack access to safe drinking water, namely 1.1 billion people, and more than two out of six lack adequate sanitation, namely 2.6 billion people (Estimation for 2002, by the WHO/UNICEF JMP, 2004). 3900 children die every day from water borne diseases (WHO 2004). Consequently, it must be emphasized that these figures represent only people with very poor conditions. Such figures, in reality, should be much higher.

Additionally, although food security has been significantly increased in the past thirty years, water withdrawals for irrigation represent 66 % of the total withdrawals and up to 90 % in arid regions, the other 34 % being used by domestic households (10 %), industry (20 %), or evaporated from reservoirs (4 %).

Hence, the demand of water per person increases due to changes in lifestyle and as population increases as well, the proportion of water for human use is increasing. Such an action, coupled with spatial and temporal variations in water availability, means that the water to produce food for human consumption, industrial processes and all the other uses is becoming scarce. It is all the more critical that increased water use by the people does not only reduce the amount of water available for industrial and agricultural development, but has a profound effect on aquatic ecosystems and their dependent species. Environmental balances are disturbed and cannot play their regulating role anymore. Besides, water stress results from an imbalance between water use and water resources. The water stress indicator in this map measures the proportion of water withdrawal with respect to total renewable resources. It is a criticality ratio, which implies that water stress depends on the variability of resources. Moreover, water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.). The value of this criticality ratio that indicates high water stress is based on expert judgment and experience. It ranges between 20 % for basins with highly variable runoff and 60 % for temperate zone basins. Additionally, it is well known that water stress situation is heterogeneous over the world.

Whatever the use of freshwater (agriculture, industry, domestic use), huge saving of water and improving of water management is possible. Almost everywhere, water is wasted, and as long as people are not facing water scarcity, they believe access to water is an obvious and natural thing. With urbanization and changes in lifestyle, water consumption is bound to increase.

On the contrary, in order the growing expenses to be balanced, sustained efforts will have to be supported in order to reduce the produced quantity of water. Thus, among the main factors, leakage may be considered as the most important source of expense. It is generally thought that the amount of leakage is between 15 % and 40 % of the water supplies. The successful control of fluid losses from a pressurised pipework system requires a well planned investigatory program combined with an on going monitoring exercise executed by experienced and well trained staff.

Pipe networks for the supply of water are present in all urbanised areas. Most systems have developed and expanded as the community has grown, and are a complex mixture of the tree - like (dendritic) and looped (reticulated} pipe networks, valves, reservoirs and pumps. During the past years non-linear fluid mechanics and hydraulics problems were extensively studied by E.G.Ladopoulos [1] - [8] and E.G.Ladopoulos and V.A.Zisis [9] - [10].

Consequently, there is a necessity of assessment and validation of a real - time expert water management system for leaks control in the pipe network linking to appropriate actions in the telematics program. Moreover, some studies for real - time expert systems were published by scientists like A.K. Agrawala and S.T. Levi [11] , [12] for the design of such type of systems.

On the other hand, centrally controlled systems were 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]. Moreover, 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].

Real - time logic {RTL} is a reasoning system for real - time properties of computer based systems. RTL's computational model consists of events, actions, causality relations and timing constraints. Such a model is expressed in a first order logic, describing the system properties as well as the system's dependency on external events. The Real - Time Logic system introduces time to the first order logic formulas with an event occurrence function, which assign time values to event occurrences. Such a kind of real - time logic systems were studied by F. Jahanian and A. Mock [24] , [25].

Additionally, computer based modelling of very complex systems is an ambition continuously occuring since computers became useful tools of science and technology. The theory of large scale systems required uniform and unique model of every system component, with the purpose of integrating them into an overall system model. For this reason the principle of intelligent modelling was introduced with the purpose of system control, which incorporates every type of modelling techniques - including quantitative, qualitative or rule - based techniques. Such kind of intelligent modelling were introduced by M. Jamshidi [26], J. Dekleer and J. S. Brown [27], B. Kulpers [28] and J.A. Ress and W. Clinger [29].

Beyond the above, Real - time computing in common practice is characterized by two major criteria: deterministic and fast response to external stimulation, and both human and sensor and actor based interaction with the external world. Thus, Real - time is an external requirement for a piece of software, it is not a programming methodology. There are some special software tools for the implementation of real - time expert systems. Such real - time programming languages were investigated by several authors like R. Emnis et al. [30] , W. Fritz , V. H. Haase and R. Kalcher [31] and V. H. Haase [32].

Hence, the present investigation deals with the design of a 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. This 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 proposed real - time expert system will be non-linear in its responses and a big part of the programming language will be fourth generation real - time software. It must be emphasized, that such a Real-Time Expert System will be a valuable tool in the critical and sensitive field of Water Resources Management, and will work with the aid of modern Geographic Information Systems (G.I.S.).

2. New Theories of Pipe Networks for Water Distribution

In general, water should be recognized as a great priority. Also, one of the main objectives by the current investigation is to increase awareness of the water issue. Hence, decision-makers at all levels must be implicated. One of the 21th century main goals is to halve, the proportion of people without sustainable access to safe drinking water and sanitation. To that aim, several measures should be taken:

- guarantee the right to water.
- decentralise the responsibility for water.
- develop know-how at the local level.
- increase and improve financing.
- evaluate and monitor water resources.

Additionally, 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.

On the contrary, Geographic Information Systems (GIS) are used, extensively in many parts of the world to handle data. They provide the opportunity to store data records relating to the water supply and other utility systems. Such data includes pipe lengths, diameters, fitting records, burst records, condition gradings, water quality parameters arid customer details. Hence, information can be presented in many formats including map and tabular output.

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 several types of plastic materials, like PVC, PE, HDPE, PP, HDPP, etc. So, leakages are produced, because of the oldeness of the pipes. Moreover, 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.

Thus, 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.

3. New Contributions of Leaks Control by Step Testing Method

The most effective means of locating waste water, is established by the step testing method. According to the above method the water distribution system is divided into waste zones. (Fig. 1)

In addition, 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. Furthermore, in every gate valve {or local station - LS} will be included a flow in m^3 /sec.

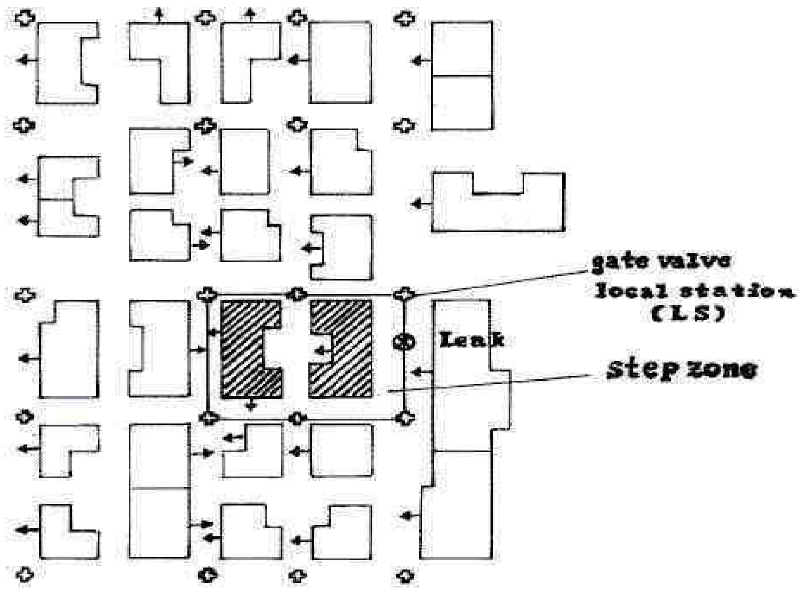

Fig. 1 Waste Zones for Step Testing Method.

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. then, 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 m^3/sec.

Hence, the recorded consumption curve shows 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)

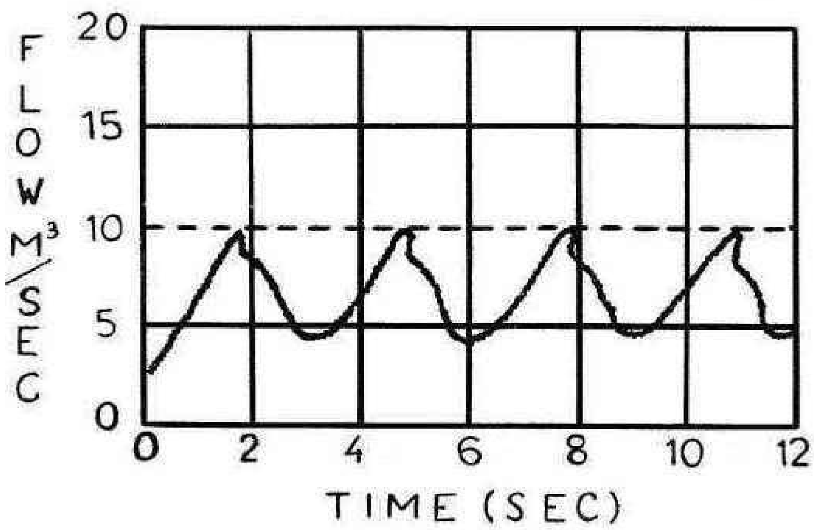

Fig. 2 Flow Diagram, when a leak exists and therefore the curve doesn't drop to zero, but repeatedly to the same minimum.

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

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

4. Contributions of Central Station (CS) for the Telematics System

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)

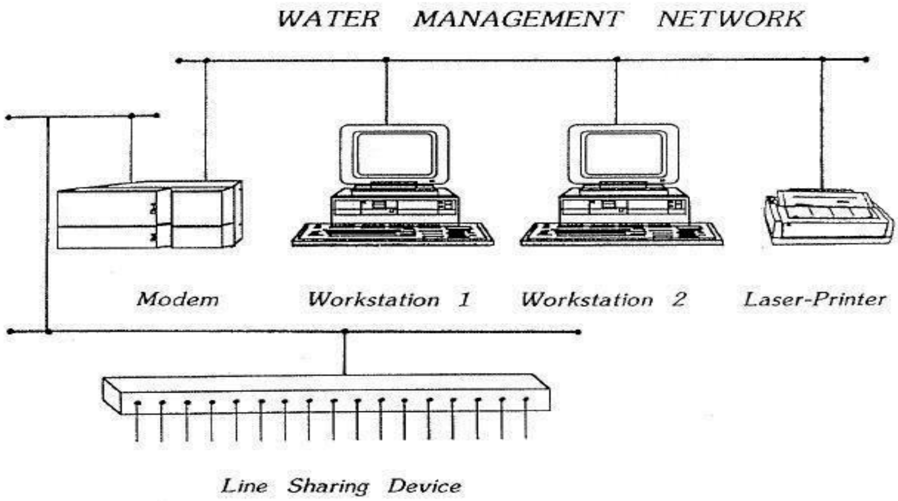

Fig. 3 Schematic Diagram of the Non-linear Real - Time Expert Water Management Telematics System.

Furthermore, ARCMAP Geographic Information Systems {GIS} working under the UNIX - operating system are used in the Workstation 1 and 2 in order to handle data. By using the ARCMAP G.I.S, the typical directories include land cover, soils imagery, topography and water information. Also, 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.

On the contrary, 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.

In addition, 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.

Finally, the Central Station of the proposed Non - linear Real - Time Expert System includes further 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.

5. New Aspects of Centrally Controlled Systems Software for the Expert System

The non- linear real - time expert system, which is proposed, is a centrally controlled system. Also, we introduce a central station i begin a synchronization produce, at a time T_1. Thus, 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 .

On the other hand, 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:

$$d_1 = C_j(T_2) - C_i(T_1) \tag{5.1}$$

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

$$C_i(T_1) + e_1 + \mu_i^j = C_j(T_2) + e_2 \tag{5.2}$$

from which follows:

$$C_j(T_2) - C_i(T_1) = \mu_i^j + (e_1 - e_2) \tag{5.3}$$

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

$$d_i = \mu_i^j + \xi_j - E_j^1 \tag{5.4}$$

Then, the process is repeated 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:

$$d_2 = C_i(T_4) - C_j(T_3) \tag{5.5}$$

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

$$C_j(T_3) + e_3 + \mu_j^i = C_i(T_4) + e_4 \tag{5.6}$$

follows:

$$C_i(T_4) - C_j(T_3) = \mu_j^i - (e_4 - e_3) \tag{5.7}$$

and as in the previous case:

$$d_2 = \mu_j^i - \xi_j - E_j^2 \tag{5.8}$$

Consequently, from eqs (5.4) and (5.8) one obtains:

$$\frac{d_1 - d_2}{2} = \xi_j + 1/2(\mu_i^j - \mu_j^i) - 1/2(E_j^1 - E_j^2) \qquad (5.9)$$

The subtraction of d_2 and d_1 can be therefore used, in order to estimate ξ_j and the correct C_j ( ).

6. New Contributions of Central Station by Unix Operating System for the Telematics System

The proposed Unix Operating System is analogous to the distributed Berkeley Unix [13], [14]. Hence, 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 can be described as following :

- Upon Initiation of Skew Measurement:

do

$T_A \leftarrow C_i \;(now\}$

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

endo

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

do

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

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

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

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

endo

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

do

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

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

Send (Δ) to j

endo

7. New Aspects of Local Station P_j by Unix Operating System for the Telematics System

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.

The two rules are the 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

8. New Contributions of Algorithm for the Maximum Error to be Minimized for the Telematics System

The proposed algorithm consists of two main rules, which are a response rule and a synchronizer rule. Hence, a request transmitted by the synchronizer rule at node j activates the response of i. In this response, node i first updates its bounds on the error, $E_i(t)$. It then replies the value $C_i(t)$ and the above bound on that error.

Moreover, the synchronizer rule is periodic, performed at least every τ time units. Its first step is a request for responses which it sends to the rest of the nodes. Then, for each of these nodes, it performs a response reception and a conditional reset. Hence, two conditions must hold for a reset:

- The interval $[C_i(t) - E_i(t), \ C_i(t) + E_i(t)]$ that expresses the local knowledge of time must be consistent with the incoming interval $[C_j(t) - E_j(t), \ C_j(t) + E_j(t)]$. The consistency requires a nonempty intersection of these two intervals.
- The error of the response, $E_j(t)$, plus the error of the response delay, $(1 + \delta_i)\mu_j^i$, generate an error smaller than the local one.

Consequently, if the above two conditions hold, then the node can reset its local station and enhance its knowledge of time. The reset involves three parameters. The local station $C_i(t)$ is set to the value of the response station. The error ε_i at local station, is set to the value of the response error and the delay combined. The time of reset record ρ_i, is also set to the value of the response station.

On the contrary, if one of the above mentioned conditions does not hold, then the algorithm ignores the response. The two rules of the algorithm are the following:

- Upon receiving a time request from $j \neq i$:

do
$E_i(t) \leftarrow \varepsilon_i + [C_i(t) - \rho_i]\delta_i$
$Send\,[C_i(t), E_i(t)]\ to\ j$
endo

- Upon receiving a time request from $j \neq i$:

do
$\forall\, j \neq i : Request[C_j(t), E_j(t)]$
for $j \neq i$ *do begin*
Receive $[C_j(t), E_j(t)]$
if $[C_j(t), E_j(t)]$ *is consistent with* $[C_i(t), E_i(t)]$
then if $E_j(t) + (1+\delta_i)\mu_j^i \leq E_i(t)$
then begin / update "/*
$C_i(t) \leftarrow C_j(t)$:
$\varepsilon_i \leftarrow E_j(t) + (1+\delta_i)\mu_j^i$
$\rho_i \leftarrow C_j(t)$
end
else ignore it
end
endo

9. New Aspects of Real-time Logic for Water Management Telematics System

The Real-time logic (RTL) is a reasoning system for real-time properties of computer based systems. RTL's computational model consists of events, actions, causality relations, and timing constraints. Hence, the RTL model is expressed in a first order logic describing the system properties as well as the systems dependency on external events. So, the RTL system introduces time to the first logic formulas with an event occurrence function denoted @. Such a function assigns time values to event occurrences.

Besides, real-time computing in common practice is characterized by two major criteria: deterministic and fast response to external stimulation, and both human and sensor and actor based interaction with the external world. Hence, it is clear that Real-time is an external requirement for a peace of software; it is not a programming technology. There are some special software tools for the implementation of real - time systems.

Moreover, RTL uses the following three types of constraints:

1. 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. In other words a transition event changes an assertion about the state

of the real-time system or its environment. The third class, which are the external events, includes those that can be impact the system behavior, but cannot be caused by the system.
2. 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.
3. Integers assigned by the occurance function provide time values, and also denote the number of an event occurance in a sequence.

Also, RTL translates assertions about the physical state of the system over time into **algebraic relations**. Such relations describe the occurrences of the appropriate transition events, using equality and inequality predicates. RTL uses state predicates as a notation device for asserting truth-values to attributes during a time interval.

There is a set of axioms from the event-action model of the system, by translating the system specifications and characterizing following properties:

a. Relations between actions and their start/stop events.
b. The sporadic and periodic event constraints.
c. The cause relations which may initiate a transition event.
d. Some artificial constraints can be added to the specification, in order to prevent the scheduler from executing particular actions. This is a useful way to prevent execution of actions that are not required.

Finally, consider the following example: Upon pressing button ≠ 1, action TEST is executed within 800 time units. Dusting each execution of this action, the information is sampled and subsequently transmitted to the display panel. Furthermore, the computation time of action TEST is 400 time units.

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

$$\forall\ x : @(\ \Omega\ \text{button}\ 1,\ x) \le @(\uparrow \text{TEST}, x) \wedge$$
$$@(\downarrow \text{TEST}, x) \le @(\ \Omega\ \text{button}\ 1,\ x) + 800$$
$$\forall\ y : @(\uparrow \text{TEST}, y) + 400 \le @(\downarrow \text{TEST}, y)$$

and safety assertions are then derived.

10. New Contributions of Artificial Intelligence for Real-Time Telematics System

In order to describe the behavior of a physical object there is indispensable 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 following form:
If < condition on assertions > then < fact >

Furthermore, the rules in classical rule based expert systems are expressed on the basis of assertions, which are objects holding true or false values. A slight modification of the form of rules make them suitable to describe deeper knowledge of an expert - system. The new form of the rules is as following:

If < an expression to be evaluated true or false >
then < fact or action >

Generally, 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.

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.

11. Conclusions

According to the current study a sophisticated technology has been further improved for 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 ground pipe networks, because of the leakage. This Real-time Expert System consists of a Centrally Controlled System with several Local Stations (LS) which are the gate valves of the pipes. The expert 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. So, 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.

Additionally, ARCMAP Geographic Information Systems (GIS) working under the UNIX-operating system in X - Windows are used in the Workstation of the Central Station (CS) in order to handle data. 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.

By the present investigation we specified a real-time system behavior with logical and temporal properties. The logical properties can be expressed by liveness and safe assertions. Each liveness property states that an assertion on the system state will eventually hold. Each safety property states that an assertion on the system state will always hold. These assertions can describe states of subsystems or relations between them. A real-time property states hat an assertion on the system state holds within time bounds.

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