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Remote-control and Supervision of Irrigation Systems: An Attempt to Better Water Management

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Abstract: This study deals with the control of an irrigation system in order to insure a good management of water use. In a first step, the control problem of open irrigation channels was considered. To this end, a fuzzy controller for an irrigation channel was developed to control the flow released from the dam to satisfy a set flow specified at the downstream of the system as well as the demand of the users at different points of the withdrawal. In a second step, a supervision stage dedicated to agricultural irrigation systems was proposed. The objective was to control the water distribution in different parcels to irrigate. To this end, the considered water management system, its equipment and its control software architecture were presented. A functional study of the system was achieved using the GTST-MPLD method (Goal Tree Success Tree-Master Plan Logical Diagram). Finally, supervision tools associated with the developed irrigation system were exposed.

Key words: Irrigation system, water management, supervision, fuzzy regulation, functional analysis

INTRODUCTION

Food and water security is the most crucial problem for both developed and developing countries. A better water management is more than urgent given the increasing need for food and the rising competition between its users, to meet their agricultural, industrial and domestic needs. For instance, the efficiency of water use in agriculture must be improved considering the increase of irrigable surfaces in order to optimize the production. A better distribution of water over space and time is required. Irrigation consumes more than 80% of the water resources world wide, with an efficiency of almost 50%^[1].

Several research have considered the supervision and hybrid control accommodation method applied to water management^[2]. However, to the best of the authors' knowledge, no system dedicated to the control and supervision of the water flow and the irrigation from a dam at a distance has been reported in the literature. In order to provide water in exact necessary quantities for the plants at the desired time, this paper proposes an approach to optimise the water management through the use of a fuzzy logic controller and the integration of a supervision stage for agricultural irrigation systems located far from the site of the dam.

PRESENTATION OF THE SYSTEM

The goal of the water management system is the real-time control of the distribution of water taking into account economic constraints. To this end, the following are requirements which must be verified by the system:

- The system must have data about exact needs in water of the plants,
- The system must have data about the available water resources in quantity as well as in quality,
- The system must evaluate the withdrawals for the different users,
- The system must follow the policies of water management pursued at mid-and long-terms,
- The system must react quickly when facing situations of crisis (flooding, drought, etc.).

Figure 1 represents a channel composed of a dam, in which are stocked reserves of water, in interconnected millraces with control valves^[3]. A millrace is a reservoir delimited by two valves.

Based on the previous diagram and taking into account several factors such as the cost of instruments, of installation and maintenance that affect the design of the automatic system^[4], we proposed a water management

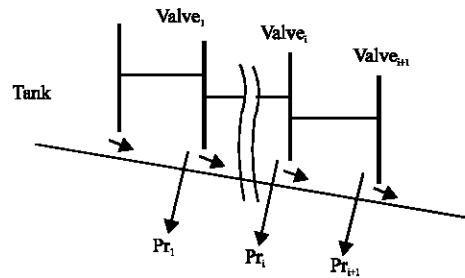


Fig. 1: Diagram of an irrigation channel^[3]. Pr_i : the withdrawal of the i^{th} millrace

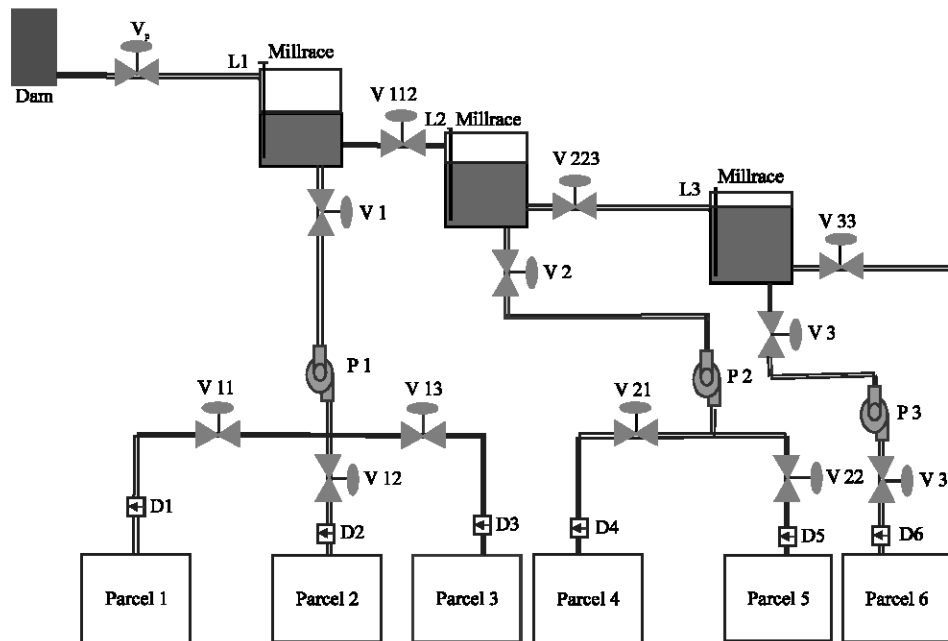


Fig. 2: Overall diagram of the water management system

system whose block diagram is given in Fig. 2. This system includes a main control valve V_p , valves fully open or closed (V_{112} , V_{223} , ...), level indicators L_i , pumps P_i , flow meters D_i and tensiometers H_{ij} .

To satisfy simultaneously the flow specified at the downstream of the system and the users' demand at different points of withdrawal, a water flow regulation is necessary. In fact, this regulation allows the delivery of given quantity of water in accordance with the exact need of plants in every parcel. To this end, it is necessary to control the water in the soil by a suitable sensor. The most operational control tool is the tensiometer which can provide indications on the evolution of the soil state. Two measurement methods could be considered. The first one is based on the measurement of the water stress value indicating the plant deficiency in water. It consists in using a radio-thermometer for measuring the temperature

of the total plant surface. A lack of water results in a difference of temperature between the plant and the ambient air. The second method is the measurement of the micrometric variations in the diameter of the stems^[5]. These two methods can provide precise measurements. However their cost is very high. The regulation of the water flow offers a partial solution to the water management problem. To solve the whole problem, a supervision mechanism must be integrated to detect faults, diagnose their source and correct them.

MODELLING OF WATER TRANSPORTATION SYSTEM

An identification of a system is required when conventional correction algorithms are used. This could be avoided considering a fuzzy controller. In practice, the

identification is useful for the adjustment of the parameters of a fuzzy controller.

In this study, we considered a second order system obtained from the equations of water transportation for free surface in order to synthesise the fuzzy controller of the water flow.

The water transient outflow in a channel can be described by the model of Saint-Venant while assuming that the outflow is one-dimensional and that the vertical accelerations are not significant^[6,7]. Thus, the transient outflow was established by the equations of mass conservation (continuity equation) and quantity of movement (dynamic equation).

Continuity equation: Let's consider a section of a channel limited between the coordinates x and $x+\Delta x$, as shown in Fig. 3.

In Fig. 3, S is the wet section, x represents the space variable, Q designates the flow through section S , q represents the lateral flow by unit of length, v is the medium speed of water and L is the width of the channel.

During a time variation Δt , the equation of mass conservation was obtained from the equality between the variation of water storage during the time Δt and the difference between the input and output of water mass in a fragment of the channel:

$$\rho(S \Delta x)_{t+\Delta t} - \rho(S \Delta x)_t = \rho(Q \Delta t)_x + \rho q \Delta z \Delta t - \rho(Q \Delta t)_{x+\Delta x} \quad (1)$$

where, ρ represents the volume weight.

By setting x and t to their limits, we get the following continuity equation:

$$\frac{\partial S(x,t)}{\partial t} + \frac{\partial Q(x,t)}{\partial x} = q \quad (2)$$

Dynamic equation: Applying the principle of the quantity of movement to volume V of water delimited between sections x and $x+\Delta x$ and while projecting this equation on the x axis of the channel, yields the following dynamic equation^[1]:

$$\frac{\partial Q(x,t)}{\partial t} + \frac{\partial v Q(x,t)}{\partial x} + g S \frac{\partial Z(x,t)}{\partial x} = -g S J + k v q \quad (3)$$

where, $Z(x,t)$ represents the coast of the wet surface.

Therefore, from equations and the model of Saint-Venant can be described by:

$$\begin{cases} L \frac{\partial Z(x,t)}{\partial t} + \frac{\partial Q(x,t)}{\partial x} = q \\ \frac{\partial Q(x,t)}{\partial t} + \frac{\partial v Q(x,t)}{\partial x} + g S \frac{\partial Z(x,t)}{\partial x} = -g S J + k v q \end{cases} \quad (4)$$

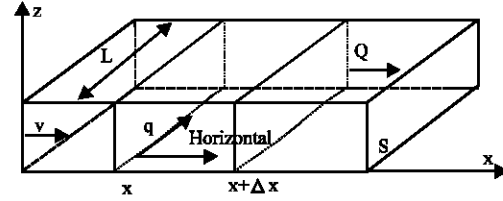


Fig. 3: Channel section representation

It is to be noted that the model of Saint-Venant, in spite of simplifying hypothesis, remains relatively complicate especially when the design of a control system is considered. Hayami proposed a simplified model which describes the water outflow in the channel.

Hayami model: Considering some assumptions, Hayami proposed the following model^[8]:

$$\begin{cases} L \frac{\partial Z(x,t)}{\partial t} + \frac{\partial Q(x,t)}{\partial x} = 0 \\ \frac{\partial Z(x,t)}{\partial x} = -J \end{cases} \quad (5)$$

Differentiating, with respect to x , the first equation of system and differentiating, with respect to t , the second equation of system and eliminating the function $Z(x,t)$ give the following equation:

$$\frac{\partial Q(x,t)}{\partial t} + \theta \frac{\partial Q(x,t)}{\partial x} - E \frac{\partial^2 Q(x,t)}{\partial x^2} = 0 \quad (6)$$

which represents a second order partial derivative equation whose type is parabolic. This equation represents the convection and the diffusion of function $Q(x,t)$. θ and E represent the speed and the acceleration, respectively. They are function of parameters L and J , that depend on Q and Z .

The following step consists in determining $F(x,p)$: the transfer function linking the flow $Q_e(p)$ released in the upstream and the flow $Q_s(x,p)$ in the downstream, situated at the distance x :

$$F(x,p) = \frac{Q_s(x,p)}{Q_e(p)} \quad (7)$$

Considering the properties of Laplace transform and the limit conditions, $x = 0$ and $x = \infty$, $F(x, p)$ can be expressed by:

$$F(x,p) = \exp \left[\frac{x\theta}{2E} \left(1 - \sqrt{1 + \frac{4E}{\theta^2} p} \right) \right] \quad (8)$$

This expression is useless because of its non linearity. Therefore, its approximation by a second order function with a pure delay has been proposed by Hayami^[8]:

$$F(p) = \frac{e^{-\tau p}}{1 + 2\xi \frac{p}{w_n} + \left(\frac{p}{w_n}\right)^2} \quad (9)$$

FUZZY CONTROLLER

The focused target consists of an equitable distribution of the flow released at the dam to satisfy at the same time, a flow specified at the downstream of the system and the demand of the users in different points of withdrawal. It will be achieved through a fuzzy control of the main valve V_p ^[9].

Features of the control law: In most if not all cases, the solution of the problem under study consists in managing the required water quantity for the irrigation at the level of the dam, under the following conditions^[10,11].

- Constraints on the magnitude and on the variation of the control law. The outflow at the valve is submitted to a limitation Q_{max} on one hand and it is necessary to avoid any abrupt variation of the flow, $|\Delta Q(k)| \leq \Delta Q_{max}$ on the other hand,
- Withdrawals at the level of the pumping done on request. Therefore, the user is not subject to any timetable constraint,
- Respect of a set flow (reference) at the downstream of the system.

In the present research and for the sake of simplicity, the study is limited to one millrace in a first case and to three millraces in cascade in a second case. This has been carried out using a control law in the upstream of the system.

Case of one millrace: The block diagram of a millrace control loop is shown in Fig. 4.

The inputs of the fuzzy controller are the error $\epsilon(t)$ and its variation with respect to time $\Delta\epsilon(t)$.

Let us assume that the variation range of the flow delivered by the channels is limited in the following range $[0-3 \text{ m}^3 \text{ sec}^{-1}]$.

A Mamdani fuzzy controller with triangular membership functions has been chosen^[12].

In order to select the number of membership functions, a test have been carried out and have led to

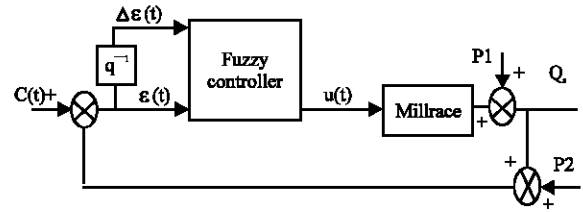


Fig. 4: Control principle for only one millrace, P1: Random disturbance, P2: Measured disturbance

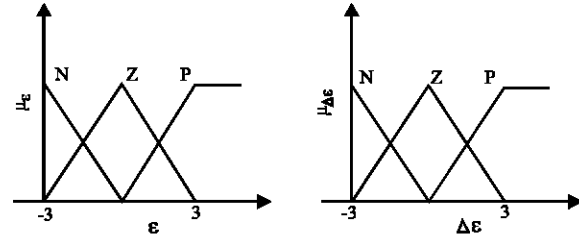


Fig. 5: Membership functions of the controller inputs

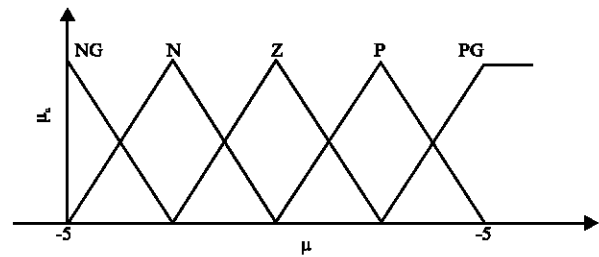


Fig. 6: Membership functions of the controller output

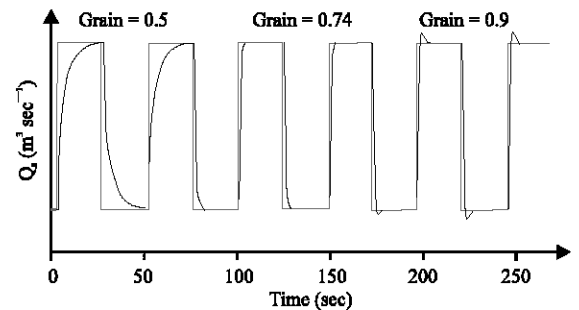


Fig. 7: Variations of the reference and the output of only one millrace without disturbance

three functions for the inputs, (Fig. 5) and five functions for the output, (Fig. 6). For instance, if the error ϵ and its variation $\Delta\epsilon$ are positive, then u is positive big (PG).

The profiles of the flow and the control law at the downstream of the millrace are illustrated in Fig. 7. Q_s represents the controlled output without disturbance of the process for different gains (0.5, 0.74 and 0.9).

This type of fuzzy controller is equivalent to a PI controller. The integrator annuls the static error and the proportional gain acts on the time response.

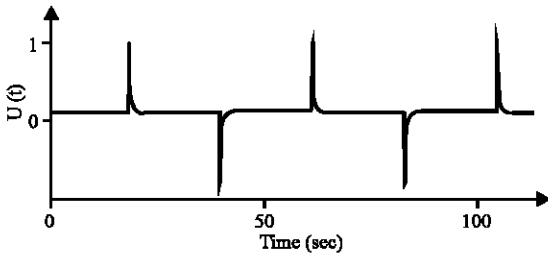


Fig. 8: Evolution of the control law

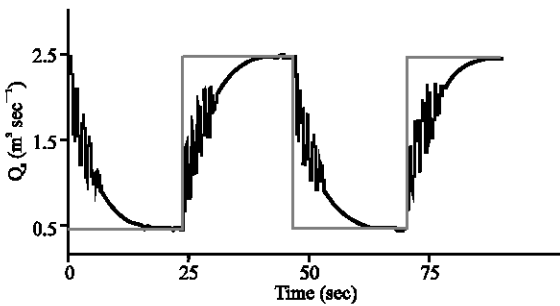


Fig. 9: Variations of the reference and the output of only one millrace with non measurable disturbance (P1)

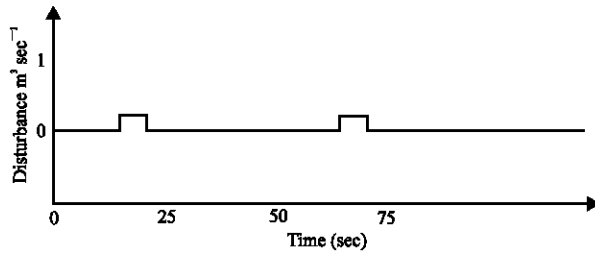


Fig. 10: Measurable disturbance (P2)

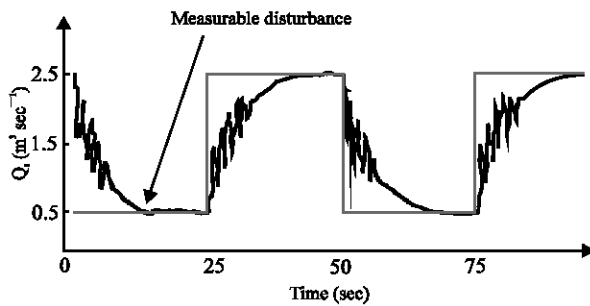


Fig. 11: Variations of the reference and the output of only one millrace with two disturbances (P1 and P2)

During changes of the control law $u(t)$ does not present any oscillations for a gain of 0.74, (Fig. 8). Besides, the variation of $u(t)$ remains within the limits of the constraint. In order to verify the robustness

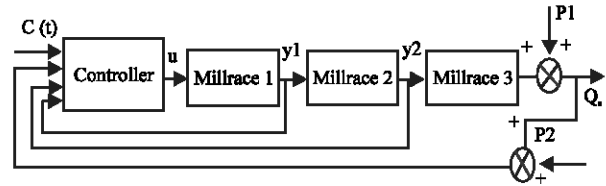


Fig. 12: Block diagram of the control loop in the case of three millraces. P1: Random disturbance, P2: Measurable disturbance

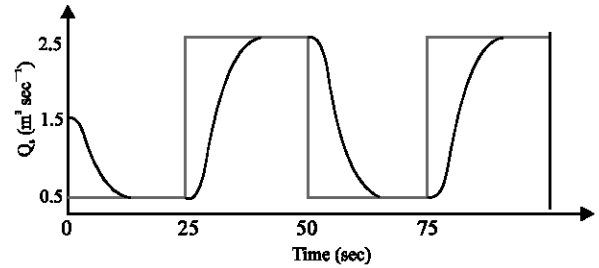


Fig. 13: Variations of the reference and the output of three millraces without disturbance

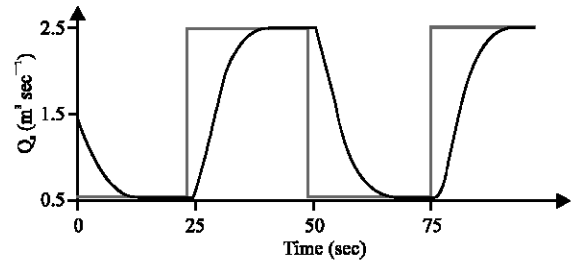


Fig. 14: Variations of the reference and the output of three millraces with disturbance (P1)

of the regulator, a white noise (P1) of null average has been added to the output of the millrace. The flow becomes as shown in Fig. 9.

Furthermore, if the system is submitted to a second measurable disturbance (P2) coming from the flow sensor, as shown in Fig. 10, the output Q_s still follows the reference (Fig. 11).

Case of three millraces in cascade: In the following, we consider the simulation of three millraces disposed in cascade. In this case, several points of withdrawal and measurements are considered (Fig. 12). For practical issues, the inputs of the controller are limited to the errors of the outputs of these millraces. One important factor is the delay on the output Q_s of the third millrace (Fig. 13). It is to be noted that the disturbance doesn't have a big effect on the output of the third millrace. This is due to the association of the millraces (Fig. 14).

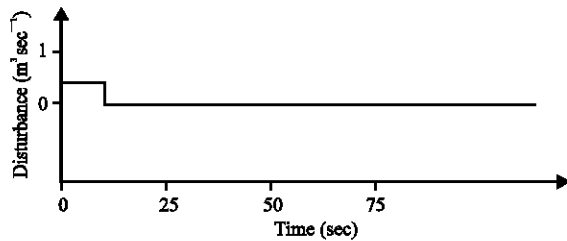


Fig. 15: Measurable disturbance (P2)

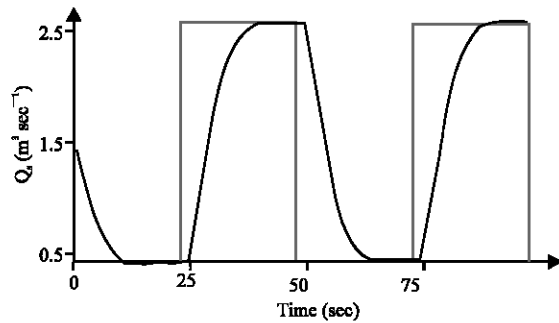


Fig. 16: Variations of the reference and the output of three millraces with two disturbances (P1 and P2)

Let us consider the case where the system of these three millraces is submitted to a disturbance (P2), (Fig. 15). One can notice that P2 is considerably attenuated (Fig. 16).

SUPERVISION SYSTEM OF THE WATER MANAGEMENT

Software architecture: A supervision stage allows the operator to control the system parameters. Two engineering solutions allow the achievement of this stage: the Numeric Systems of Control-Command (NSCC) which use the architecture of the control part to ensure the system supervision. However, facing the heterogeneity of the equipment, the lack of flexibility of this type of systems and their cost, an alternative has been selected by industrials. It deals with supervision software packages^[13].

Several softwares are available in the market, such as: FIX32, BRIDGVIEW, PANORAMA, WIZCON and INTOUCH. The last one is considered in this study, because it is often used for the supervision of the industrial processes.

Just like most if not all supervision softwares, InTouch offers the possibility of interfacing with other Microsoft softwares. Of particular interest is the interface between Matlab and InTouch which has been considered in this study. This interface has been

developed using the DDE protocol (Dynamic Data Exchange).

Functional study of the system: The conception of a supervisor must have a preliminary step of analysis and modelling of the installation. The system can be studied according to three criteria: functional, structural and behaviour^[14,15]. We select the functional because it seems the most suitable for the considered study. The goal of the functional analysis is to understand the installation and the operation. To understand the process, we go through the definition of the assigned objectives and the manner in which they are achieved. This study requires the description of the functions of the process and the relations that link them to achieve a given objective. Therefore, the objective of this step is to formalize the functional architecture of the process by decomposing the functions in sub-functions. Eventually, one can propose a functional model from which will be extracted useful information for the conception of the applications of supervision.

The general operation principle is the dam provided with a regulator supplies the three millraces with water. The routing of the water toward the millraces and the users is done by gravitation. Once arrived to the valley, this water is distributed to the different parcels through pumps and floodgates. The irrigation decision is taken in consideration according to the indication of the tensiometer which takes into account the type of crop in every parcel. Therefore, the amount of water to be distributed differs from one parcel to another.

This knowledge of the system allows to make the functional analysis leading to the GTST-MPLD model (Goal Tree Success Tree-Master Plan Logical Diagram). This model allows a hierarchical functional modelling of the complex systems under the shape of a functional tree representing the goals, the functions and the components^[16].

The GTST-MPLD model is given in Fig. 17. It presents the ties between different components of the process. We notice that this model which is clear and simple allows the understanding of the operation of the process. We also notice that this model is adapted to the surveillance and the diagnosis since we can determine, in case of system component failures, the functional part that would be affected. This representation will be useful for the conception of the supervision stage. It represents a tool adapted to the supervision by human operators. The follow-up of the good operation of the installation can be determined solely by the follow-up of the basic functions of the process.

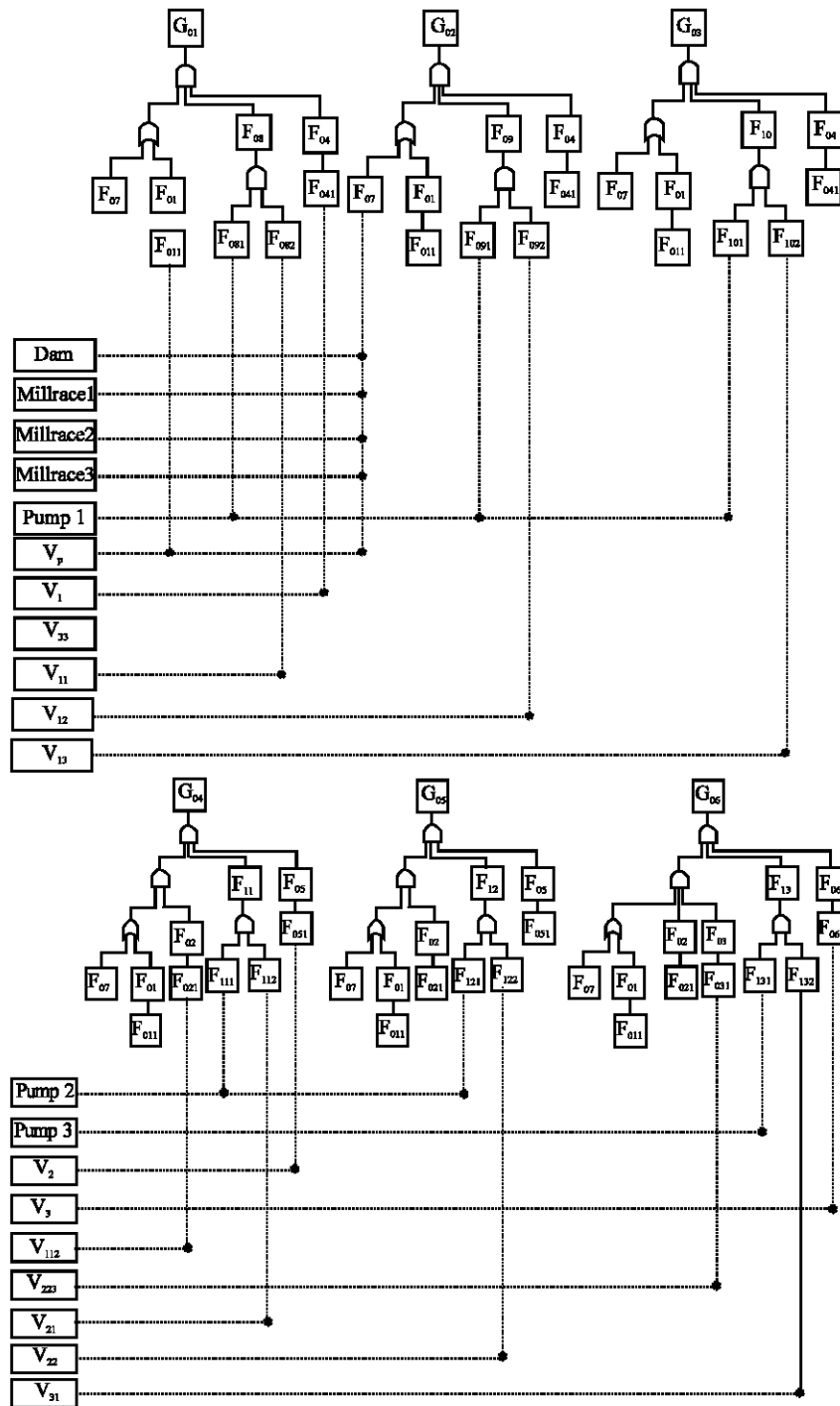


Fig. 17: The system model GTST-MPLD for three millraces

G_0 : water is provided to the plants in the required quantities and at the desired time. This goal corresponds to the global objective of the installation:

G_{0i} : water is provided to the i^{th} parcel in the required quantities and at the desired time, with i varies of 1 to 3 for the millrace1, of 4 to 5 for the millrace2 and $i = 6$ for the millrace3.

F_{01} : supply water to the millrace1; F_{011} : act on the V_p floodgate; F_{02} : supply water to the millrace2; F_{021} : act on the V_{112} ; F_{03} : supply floodgate water to the millrace3; F_{031} : act on the V_{225} ; F_{04} : supply floodgate water to the valley 1; F_{041} : act on the V_1 ; F_{05} : floodgate: to bring water in the valley 2; F_{051} : act on the V_2 ; F_{06} : supply floodgate water to the valley 3; F_{061} : act on the V_3 ; F_{07} : regulate the floodgate flow to the exit of the dam; F_{08} : to run the water of the entry of valley 1 toward parcel1; F_{081} : set the pump P_1 on; F_{082} : act pump on the V_{11} ; F_{09} : floodgate: to make circulate the water of the entry of the valley 1 toward the parcel2; F_{09} : set the pump P_1 on; F_{092} : act pump on the V_{12} ; F_{10} : floodgate: to make circulate the water of the entry of the valley 1 toward the parcel3; F_{101} : set the pump P_1 ; F_{102} : act pump on the V_{13} ; F_{11} : floodgate: to run the water of the entry of the valley 2 toward the parcel4; F_{111} : to start P_2 ; F_{112} : act pump on the V_{21} ; F_{12} : floodgate: to run the water of the entry of the valley 2 toward parcel5; F_{121} : start P_2 ; F_{122} : act pump on the V_{22} ; F_{13} : floodgate: to run the water of the entry of the valley 3 toward the parcel6; F_{131} : start P_3 ; F_{132} : act pump on the V_{31} floodgate

DEVELOPMENT OF THE SUPERVISION SYSTEM

The surveillance of the system of the water management is made up of five views:

- One global view
- Three valley views
- One view detected to tendencies and alarms^[17].

Global view: A global view of the system includes links of direct access to the other views representing the parcels of each of the three valleys, (Fig. 18). On this view are displayed the normal, correction and alarm states. The blinking red colour corresponds to the alarm state. The yellow colour corresponds to the correction state and the blue colour corresponds to the normal state. Furthermore, different levels of water in the millraces are displayed on the monitor. In addition, the operator has the possibility (i) to select the previous information of the water withdrawals for every user, (ii) to consult the list of the alarms and (iii) to choose the operation mode of the system. The system can be operated manually or automatically. For the manual mode, the operator has the possibility to act on the actuators of the system (valves,

pumps, etc.). In the automatic mode, the system operates according to an established program in the script of the software "InTouch". At this stage, the operator can act directly on the system only in an emergency situation (breakdown, failure of one of the components, etc.) and then he switches to the manual mode.

For the regulation of the valve V_p , a reference is always needed. This latter is calculated by adding the references (required water flow) of all the millraces. This value is given by the tensiometer (Hij) according to the state of soil. The different values of the soil humidity securities of the water are classified in to three categories:

- First category: It represents the saturated of continuous. Soil is saturated in water. Therefore irrigation is stopped.
- Second category: Soil begins to drain. This category is indicated by humidity values lying between the minimum threshold and the maximum one. Irrigation can continue.
- Third category: It represents a dangerous zone for the plant because soil is going to dry up very quickly. Irrigation is urgent.

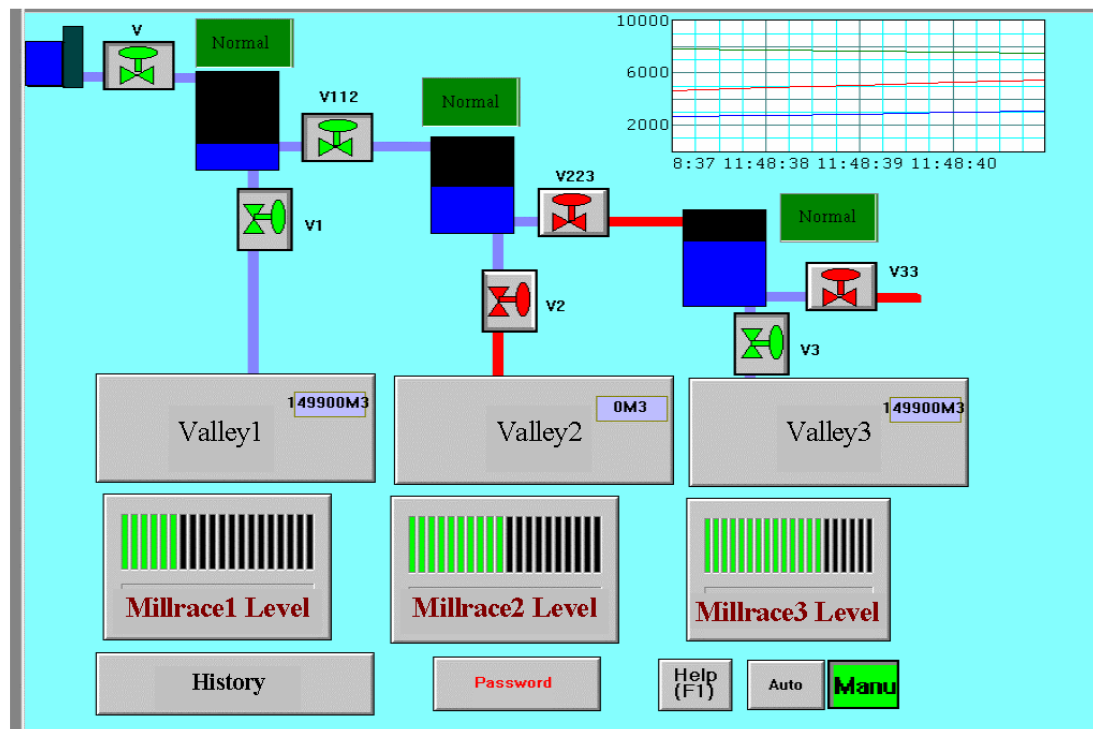


Fig. 18: Global view of the water management system

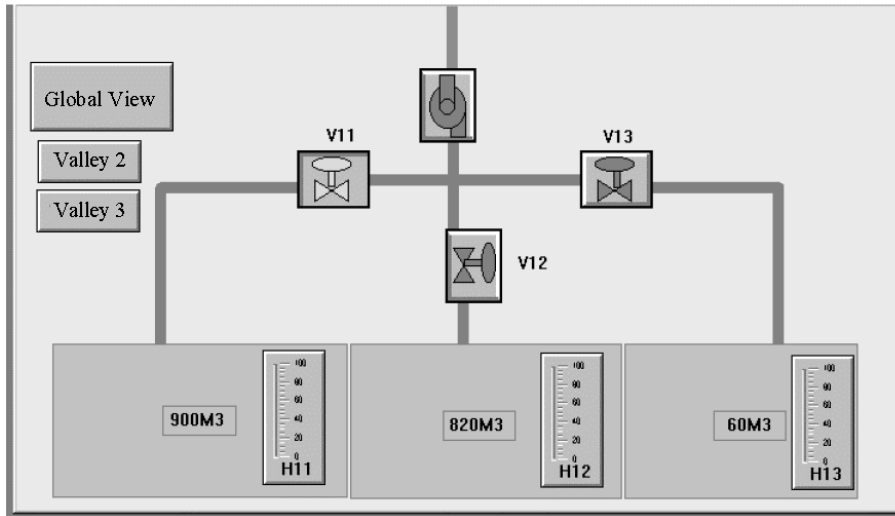


Fig. 19: The view of valley 1

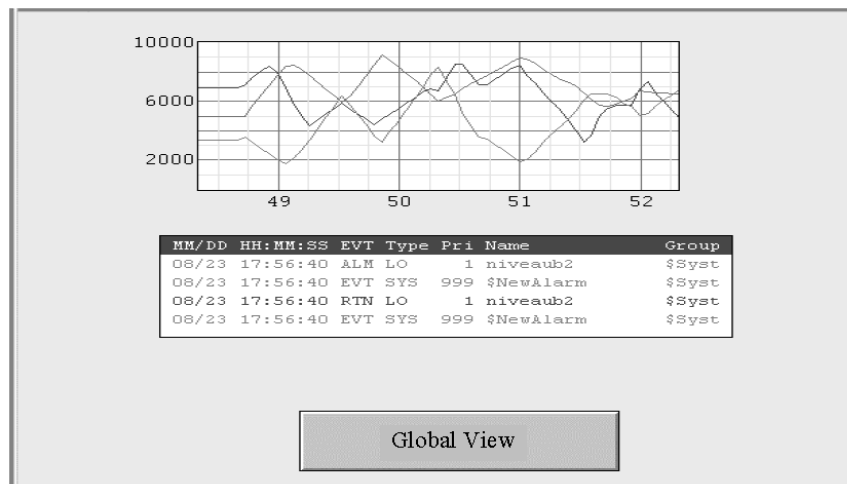


Fig. 20: The view of alarms and tendencies

Views of history and alarms: This view includes the history of the withdrawals for each user, while displaying the list of the states of the different programmed alarms. It deals with the alarm of low and high levels of water in each millrace (Fig. 19 and 20).

CONCLUSIONS

Water is becoming more and more rare because of the increase of its consumption. In the case of the management of the irrigation water, the lack of a servo system capable to take into account all situations (shortage of water, drought, etc.) and to act consequently doesn't permit an efficient control of hydraulic resources.

In order to solve this problem, we conducted a conceptual work based on the fuzzy regulation of the flow of an agricultural irrigation channel and on the tools of supervision for the system operation that permits the distribution of the water from the main source to the plant. This system takes into account the reserves of available water in every millrace, the quantity delivered to every parcel using flow meter and the humidity of the soil detected by a tensiometer giving the need of the plants in water.

The results of the functional analysis have been exploited for the design of a supervision stage of a water management system which has been implemented in the InTouch environment. This stage permits to control the

hydraulic resources in order to provide a perfect satisfaction to the demands in water.

This said, the development of a model describing the need of the plant at a given time remains a problem that hinders a complete automation of the water management system. An approach to solve this problem based either on (i) a multi-model structure for the plant, reproducing its behaviour especially its water needs in different periods of the year, or on (ii) an expert system that takes into account the life cycle of the plant, could be treated in the future.

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