TEST OF AUTO-TUNED AUTOMATIC DOWNSTREAM CONTROLLERS ON GIGNAC CANAL

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ABSTRACT

The paper extends the automatic tuning method proposed by the authors for the case of a single pool to the case of multiple-pool canal. The relay experiment is used to automatically compute the decouplers, and the controller is automatically switched on after the relay test, leading to a set of decentralized distant downstream PI controllers with decouplers. The method is evaluated in simulation and in reality on a large scale irrigation canal pool located in the South of France.

INTRODUCTION

The modernization of irrigation canals requires to easily implement and tune downstream controllers. Even for simple controllers such as PI controllers, the tuning process is usually done by trial and error, which is time consuming, and not a straightforward procedure. It would be desirable to have a straightforward method to tune such simple controllers for an irrigation canal. Litrico et al. (2007) proposed to use the Auto Tune Variation (ATV) method initially developed by Astrom and Hagglung (1984), to tune PID controllers for an irrigation canal pool. This method enables to identify important characteristics of the frequency response of the canal pool by using a simple relay experiment.

The objective of the paper is to extend this automatic tuning method to the case of multiple pools irrigation canals, by automatically computing the decoupler value. The relay experiment is used to automatically compute the decouplers, and the controller is automatically switched on after the relay test, leading to a set of decentralized distant downstream PI controllers with decouplers. The method is evaluated in simulation and in reality on a large scale irrigation canal pool located in the South of France.

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PROBLEM DESCRIPTION

Notations

For pool *i* we denote u_i the control variable at the upstream end, u_{i+1} the control variable at the downstream end, y_i the controlled variable (water depth at the downstream of pool *i*).

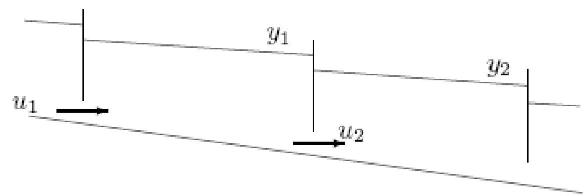

Figure 1. Schematic longitudinal view of an irrigation canal with two pools

The linearized Saint-Venant equations lead to the following frequency domain representation for one canal pool:

$$y_i(s) = G_i(s)u_i(s) + \widetilde{G}_i(s)u_{i+1}(s) \tag{1.}$$

A simple approximation of transfer functions $G_i(s)$ and $\widetilde{G}_i(s)$ is given by the Integrator Delay model, leading to:

$$G_i(s) = \frac{e^{-\tau_i s}}{A_i s} \tag{2.}$$

$$\widetilde{G}_i(s) = -\frac{1}{A_i s} \tag{3.}$$

with τ_i the time-delay for downstream propagation and A_i the equivalent backwater area. The delay τ_i and the integrator gain can be obtained analytically from the hydraulic parameters of the pool (see Schuurmans et al., 1999, Litrico and Fromion, 2004).

Description of ATV Tuning Method

The relay feedback auto-tuning proposed by Astrom and Hagglung (1984) was one of the first to be commercialized for tuning of PID controller in industry. It has since remained attractive owing to its simplicity and robustness. In this method, the process to control is connected in a feedback loop with a relay, as shown in Figure 2.

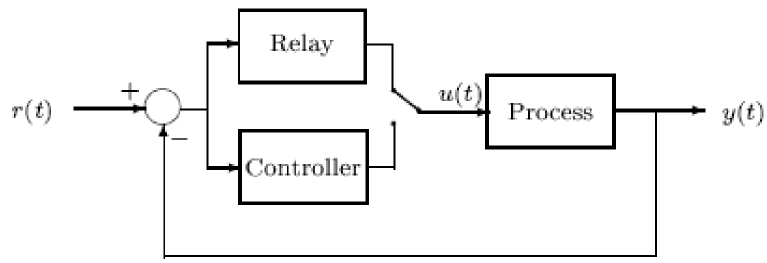

Figure 2. Relay feedback system

The objective of the method is to determine from a single experiment the critical point, i.e. the process frequency response at the phase lag of *-180°*. It can be shown that under relay control as in Fig. 2, the process will oscillate with the period T_u and that the critical gain k_u is approximately given by:

$$k_u = \frac{4d}{\pi a} \tag{4.}$$

where d is the relay amplitude and a is the amplitude of the process output (Astrom and Hagglung, 1984).

Typical responses are as in Fig. 3. The relay is a simple nonlinear element that changes the input to $-d$ when the output error becomes negative, and to d when the error becomes positive. It is therefore very easy to implement on a real canal, since the gate opening has to be opened or closed according to a measured water level.

The relay amplitude d is positive when dealing with downstream control and it is negative when dealing with upstream control.

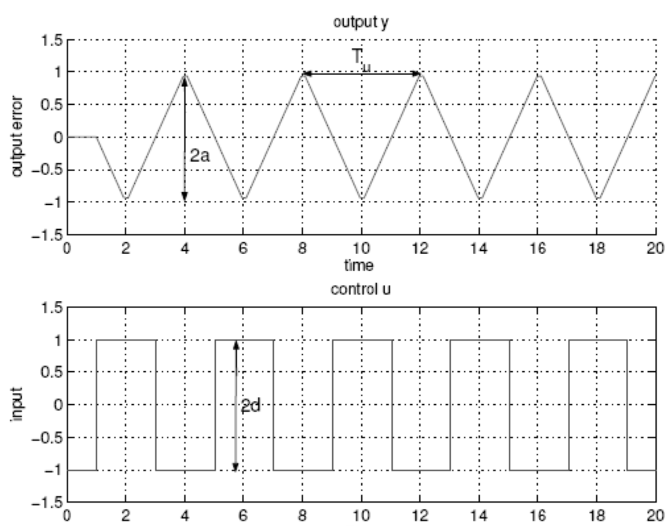

Figure 3. Simulation of a relay experiment on a dimensionless Integrator Delay system.

In the following, since we deal with multiple pools, we will denote by a superscript $^{(i)}$ the parameters corresponding to pool i of the considered canal.

AUTOMATIC TUNING OF DOWNSTREAM CONTROLLERS

Case of a Single Pool

The canal pool approximated by an Integrator Delay model is then represented by:

$$y_i(s) = \frac{e^{-\tau_i s}}{A_i s} u_i(s) \tag{5.}$$

In this case, one may show that the relay experiment leads to the following values (see Litrico et al., 2007 for details):

$$k_u^{(i)} = \frac{4A_i}{\pi\tau_i} \tag{6.}$$

$$T_u^{(i)} = 4\tau_i \tag{7.}$$

Therefore the relay experiment enables to identify the ID model parameters A_i and τ_i.

Case of Multiple Pools

In the case of multiple pools controlled with distant downstream PI controllers, one may use a relay experiment to tune successively each pool. This will lead to decentralized PI controllers for the canal pool. However, it is well-known that pool interactions decrease the overall performance of decentralized controllers for an irrigation canal (Schuurmans, 1997). This is why it is interesting to find a way to compute the value of decouplers from a relay experiment. The decoupler is a constant coefficient $D^{(i)}$ that is used to compute the modification in the upstream control variable u_i of pool i to compensate for the effect of the downstream control variable u_{i+1} over the controlled variable (the downstream level y_i). The coefficient can be determined from two relay experiments:

- one relay experiment for local upstream control between u_{i+1} and y_i, leading to ultimate parameters denoted by $\tilde{k}_u^{(i)}$ and $\tilde{T}_u^{(i)}$, and
- one relay experiment for distant downstream control between u_i and y_i, leading to ultimate cycle parameters denoted by $k_u^{(i)}$ and $T_u^{(i)}$.

Then the decoupler for pool i is given by (see Appendix for details):

$$D^{(i)} = -\frac{k_u^{(i)} T_u^{(i)}}{\tilde{k}_u^{(i)} \tilde{T}_u^{(i)}} \tag{8.}$$

Furthermore, if the controllers are tuned from the downstream end of the canal towards the upstream end of the canal, it is not necessary to perform the relay experiment specifically for local upstream control. Indeed, if one denotes $\tilde{a}_i$ the amplitude of level y_i during the distant downstream experiment for pool $i+1$, then the ultimate parameters for local upstream control of pool i are given by:

$$\tilde{k}_u^{(i)} = \frac{4 d_{i+1} T_u^{(i+1)}}{\pi \tilde{a}_i T_s} \tag{9.}$$

and

$$\tilde{T}_u^{(i)} = 2T_s \tag{10.}$$

with T_s the sampling time period.

APPLICATIONS OF ATV METHOD

Description of Gignac Canal

The experiments are performed on the Gignac canal, located 40 km north-west of Montpellier, south of France. The main canal is 50 km long, with a common feeder (8 km long) and two branches on the left and right banks of the river (resp. 27 and 15 km long). The canal is concrete lined, with a rectangular cross section on the feeder and a trapezoidal one on the branches, with average slopes of respectively, 0.35 and 0.50 m/km. The design flow of the canal is 3.5 m^3/s. The canal has been equipped with sensors, actuators and a SCADA system interfaced with the SIC-SCADA real-time module of the SIC software, which enables the monitoring and control of the cross-regulators of the right bank main canal.

Experimental Results

The proposed method is applied on three pools of Gignac canal, between corss-regulators Partiteur, Avencq, Lagarel and Mas Rouvière. The location of these cross-regulators is depicted in Figure 4.

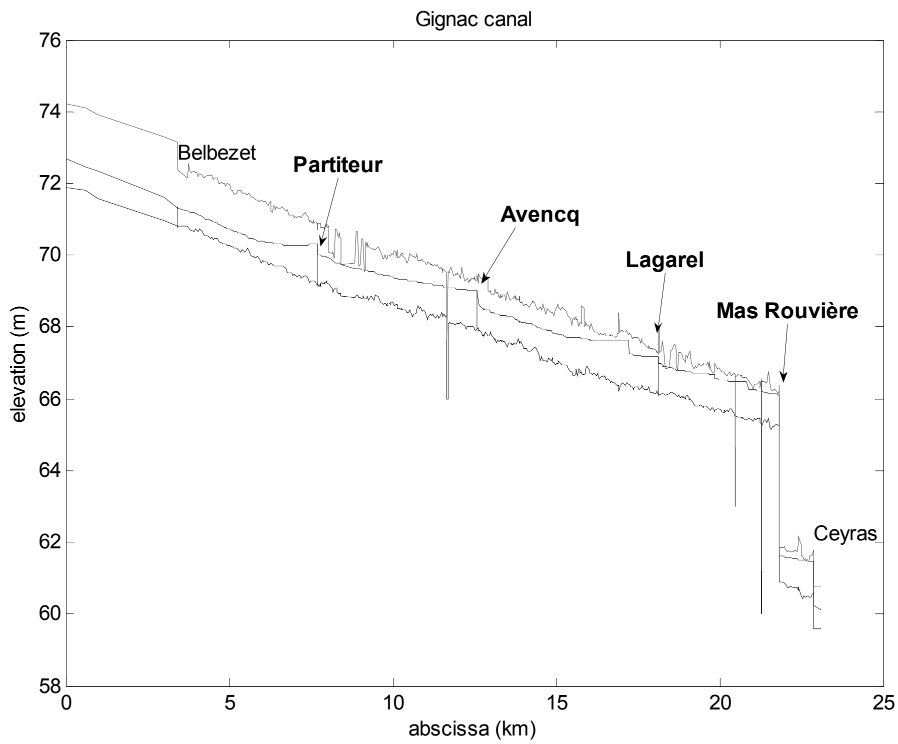

Figure 4. Longitudinal profile of Gignac Canal

The corresponding variables are denoted as follows:

- u_1 is the gate opening at Partiteur, y_1 is the water level upstream Avencq
- u_2 is the gate opening at Avencq, y_2 is the water level upstream Lagarel
- u_3 is the gate opening at Lagarel, y_3 is the water level upstream Mas Rouvière

The sampling period is chosen equal to 5 min. The controllers are tuned sequentially from downstream to upstream. After the relay experiment, the PI controllers coefficients are computed using the method proposed by Litrico and Fromion (2006), so as to ensure a gain margin of 10 dB and a phase margin of 45 degrees. The decouplers are computed using Eq. (8) of this paper, and are used to compute the gate openings at regulators Avencq and Partiteur.

The corresponding setpoints are :

- $y_c=84$ cm for the water level upstream of Mas Rouvière
- $y_c=95$ cm for the water level upstream of Lagarel
- $y_c=79$ cm for the water level upstream of Avencq

The chosen gate deviations for the relay experiment are:

- $d=5$ cm for the gate opening at Lagarel

- *d=10* cm for the gate opening at Avencq
- *d=6* cm for the gate opening at Partiteur

Once a controller is switched on, it is tested during a few hours to check its stability and performance. After this time period, the next relay experiment is done to tune the next controller and the corresponding decoupler.

The results are displayed in Figure 5 . It appears clearly that during a relay experiment, the controlled water level downstream of the pool oscillates due the relay, but so does the water level located just upstream of the gate! Therefore, one can measure the amplitude of these oscillations in order to determine the decoupler value. This is what is proposed in this paper.

As shown by the experimental results, the controllers perform correctly during the whole experiment, and lead to a good performance.

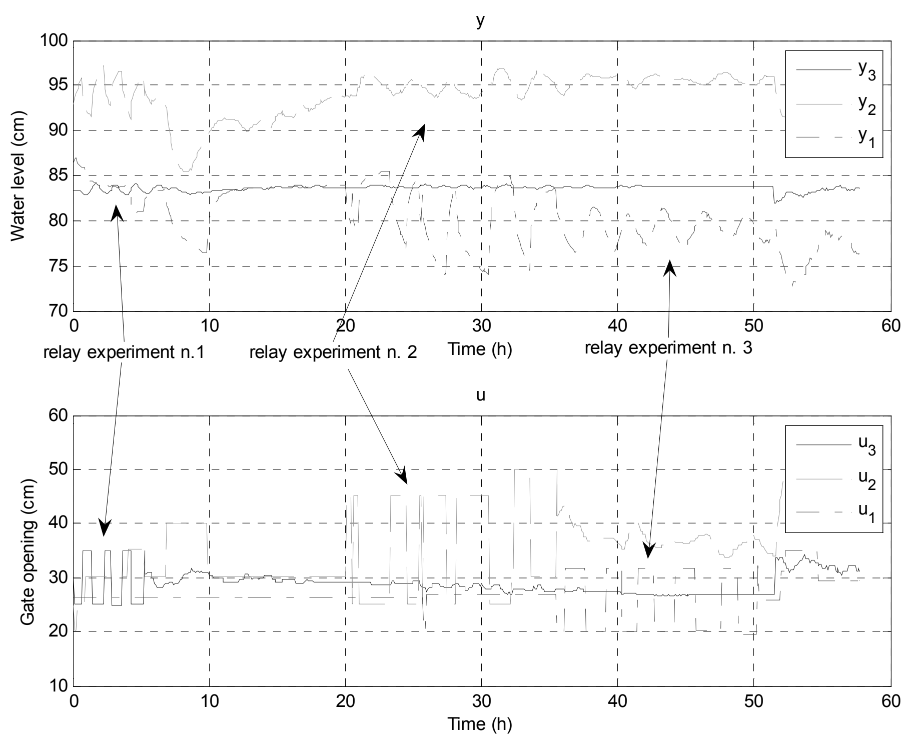

Figure 5. Relay experiments

CONCLUSION

We extended in this paper the ATV method proposed for one canal pool to automatically tune PID controllers for a multiple pools canal. The proposed method allows to automatically compute the decouplers for distant downstream control of a multiple pools canal.

The proposed method has been evaluated on three successive pools of the Gignac canal. The experimental results show the effectiveness of the approach.

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APPENDIX

Ultimate Cycle Parameters Obtained via a Relay Experiment for an Integrator Delay Model

We compute in this section the ultimate cycle parameters obtained via a relay experiment for an ID model given by equation (1). Let us examine the system behaviour in steady state with persistent limit cycle. We suppose without loss of generality that the error becomes negative at $t=0$. Due to the integrator and since this output error comes from an input negative step of amplitude d_i, the error is decreasing as a negative ramp of slope $-d_i/A_i$. Then, at $t=0$ the relay leads to a input positive step of amplitude d. At $t=\tau_i$, this positive step influences the output, which has reached the value $-d_i\ \tau_i/A_i$. Then the output increases as a positive ramp of slope d_i/A_i, during a time equal to $2\tau_i$. This is depicted in Figure 6.

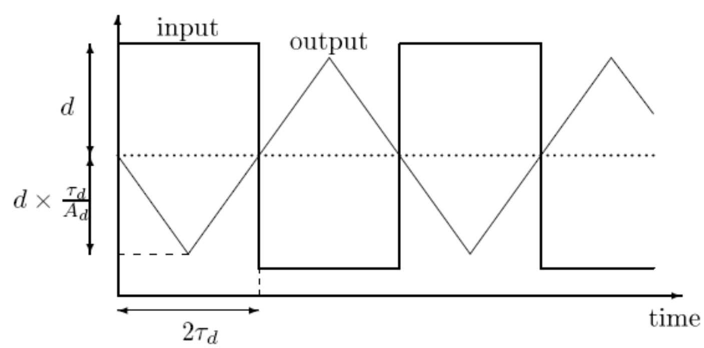

Figure 6: Relay experiment for an ID model

Therefore, the amplitude of the output is equal to:

$$a_i = d_i \frac{\tau_i}{A_i} \tag{11.}$$

and using equation (6), the ultimate parameters are given by:

$$k_u^{(i)} = \frac{4a_i}{\pi\tau_i} \qquad (12.)$$

and

$$T_u^{(i)} = 4\tau_i\,. \qquad (13.)$$

Computation of the Distant Downstream Decoupler Coefficient from the Ultimate Cycle Parameters

If the control action variable is a discharge, then the decoupler should be equal to 1. However, in many cases one may not use the discharge as a control action variable, but the gate opening. In this case, if the upstream water level is controlled, the outgoing discharge is roughly proportional to the gate opening. Let us denote k_i this proportional coefficient for gate i (upstream gate of pool i). Then, the decoupler for distant downstream control of pool i should be equal to

$$D^{(i)} = \frac{k_{i+1}}{k_i} \qquad (14.)$$

In this case, each pool controlled with the gate opening is represented by an ID model where the integrator inverse coefficient A_i is equal to

$$A_i = \frac{A_{di}}{k_i} \qquad (15.)$$

where A_{di} is the backwater area. For local upstream control, the integrator coefficient $\widetilde{A}_i$ is equal to

$$\widetilde{A}_i = \frac{A_{di}}{k_{i+1}} \qquad (16.)$$

Using results from Appendix I, each relay experiment enables to identify parameters of the ID model. For distant downstream control, one gets from Eqs. (12-13):

$$A_i = \frac{\pi}{16} k_u^{(i)} T_u^{(i)} \qquad (17.)$$

Using Eq. (15), this leads to:

$$k_i = \frac{16 A_{di}}{\pi} \frac{1}{k_u^{(i)} T_u^{(i)}} \qquad (18.)$$

For local upstream control, one gets:

$$\widetilde{A}_i = -\frac{\pi}{16} \widetilde{k}_u^{(i)} \widetilde{T}_u^{(i)} \qquad (19.)$$

(note that $\widetilde{k}_u^{(i)} < 0$), and

$$k_{i+1} = -\frac{16 A_{di}}{\pi} \frac{1}{\widetilde{k}_u^{(i)} \widetilde{T}_u^{(i)}} \qquad (20.)$$

Then, collecting Eqs. (14), (18) and (20) leads to :

$$D^{(i)} = \frac{k_{i+1}}{k_i} = -\frac{k_u^{(i)} T_u^{(i)}}{\tilde{k}_u^{(i)} \tilde{T}_u^{(i)}} \tag{21.}$$

Let us assume that the model of pool *i* is described by the following equation:

$$\tilde{G}_i(s) = -\frac{e^{-\frac{T_s}{2}s}}{A_i s} \tag{22.}$$

i.e. an integrator delay model with a delay equal to half the sampling period. This is true if the measurement point is close enough to the gate.
Then, according to equation (6), we have:

$$\tilde{k}_u^{(i)} = \frac{8\tilde{A}_i}{\pi T_s} \tilde{T}_u^{(i)} \tag{23.}$$

Parameter $\tilde{A}_i$ can be estimated either by using a relay test for local upstream control, or by using the measurements done during the distant downstream relay test between u_{i+1} and y_{i+1}. Indeed, assuming the ID model (5), the amplitude $\tilde{a}_i$ of y_i due to step variations of the control action variable u_{i+1} with period $T_u^{(i+1)}$ and amplitude $2d_{i+1}$ is given by:

$$\tilde{a}_i = \frac{d_{i+1} T_u^{(i+1)}}{2\tilde{A}_i} \tag{24.}$$

Therefore, using Eq. (23) the ultimate parameters for upstream control of pool *i* are given by:

$$\tilde{k}_u^{(i)} = \frac{4 d_{i+1} T_u^{(i+1)}}{\pi \tilde{a}_i T_s} \tag{25.}$$

and

$$\tilde{T}_u^{(i)} = 2T_s\,. \tag{26.}$$

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