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Control Engineering Practice 15 (2007) 673–686
CONTROL ENGINEERING PRACTICE
www.elsevier.com/locate/conengprac

# Fractional robust control of main irrigation canals with variable dynamic parameters

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Received 28 June 2005; accepted 30 November 2006
Available online 22 January 2007

**Abstract**

A new method is proposed for controlling main irrigation canals with variable dynamical parameters based on robust fractional order controllers. A methodology for designing PID controllers robust to changes in the time delay and the gain is presented first. Then this method is generalized to design fractional controllers that exhibit the same robustness as the previous PID to time delay and gain changes, but are noticeably more robust to variations in the dominant time constant of the process. This method is applied to control main irrigation canals. Extensive numerical simulations using the dynamic model of a real canal were carried out. Then experimental results were obtained in a prototype canal that proved the effectiveness of the proposed control method in terms of performance and robustness.


*Keywords:* Robust fractional order controllers; Irrigation canal control; Robust PID controllers; Efficient management of hydraulic resources

## 1. Introduction

Nowadays water is becoming a precious, rare and scarce resource all over the world. Thus there is a growing interest in the application of advanced management methods to prevent waste of this vital resource. Irrigation is the main water consuming activity around the world, since it represents about 80% of the available fresh water consumption. The most important objective of irrigation systems is to provide the demanded quantity of water to the different users at specified instants, and to guarantee the safety of the infrastructure (Malaterre, 1998).

Many irrigation systems are still being managed manually, leading to low efficiency in terms of delivered water versus water taken from the resource (Litrico & Georges, 1999). Automatic control leads to more efficient water management in irrigation systems which are based on open main canals subject to high losses (Kovalenko, 1983; Malaterre, 1995). The main objectives of these automatic control systems are: (1) to improve water efficiency and distribution, (2) to reduce water loss, and (3) to supply water consumers in due time.

Several control methods have been developed for water distribution canal networks: upstream control, downstream control, bival control, adjustable flow-rate control, etc. (Buyalski, Ehler, Falvey, Rogers, & Serfozo, 1991; Malaterre, 1995). Design of controllers for water distribution in main irrigation canals is a difficult task because these systems exhibit nonlinear dynamics distributed over long distances with significant time delays, and their dynamics change depending on the operating conditions (Litrico, Fromion, Baume, Arranja, & Rijo, 2005). Linear regulators are usually designed without considering robustness requirements—which are essential in time varying dynamics like these—leading to inefficient control.

The dynamics of water flowing in irrigation open canals is modeled by using the so-called Saint-Venant equations, which are nonlinear hyperbolic partial differential

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0967-0661/$ - see front matter 
doi:10.1016/j.conengprac.2006.11.018

equations and are given by (Chow, 1988)

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q;$$
$$\frac{\partial Q}{\partial t}+\frac{\partial Q^2/A}{\partial x}+gA\frac{\partial z}{\partial x}=-gAS_f+kqV, \quad (1)$$

where $A(x,t)$—canal cross section area; $Q(x,t)$—discharge through section $A$; $q(x,t)$—lateral discharge; $V(x,t)$—the mean velocity in section $A$; $z(x,t)$—absolute water surface elevation; $x$—distance along the canal; $g$—gravity acceleration; $t$—time variable; $k$—weighting coefficient, $k=0$ if $q>0$ and $k=1$ if $q<0$; $S_f(x,t)$—friction slope.

Nowadays different methods exist for the solution of the Saint-Venant equations, but all of them exhibit considerable mathematical complexities (Litrico & Fromion, 2004). Moreover, these equations are very difficult to use directly for controller design (Malaterre, 1995). Often, the Saint-Venant equations are linearized around a set point, and equivalent first-order systems plus a delay are used to model the canal dynamic behavior (Weyer, 2001). These models have the strong drawback that their parameters may experience considerable changes when the canal operation regime varies (e.g. Rivas Perez, 1990). Thus any controller to be designed for an irrigation canal has to be robust to variations in the parameters of the linearized model.

Over the past few years, fractional operators have been applied with satisfactory results to model and control processes with complex dynamics, most of them being distributed parameter processes (Machado, 1997; Odai & Hori, 2000; Podlubny, 1999; Vinagre, Podlubny, Hernandez, & Feliu, 2000). Recently, several works designed fractional PID controllers in the frequency domain with enhanced robustness properties (e.g. Barbosa, Tenreiro Machado, & Ferreira; 2004; Monje, Calderon, Vinagre, Chen & Feliu, 2004; Valerio & Costa, 2005). Robustness features in the frequency domain are also explored in this paper, and are applied to design robust controllers for effective water distribution control in main irrigation canals whose dynamic parameters vary over a wide range.

It is also worth mentioning that gain scheduling PI controllers (Bolea, Puig, Blesa, Gómez, & Rodellar, 2005) have been proposed for irrigation canals. These adaptive controllers reduce the effect of process parameter variations by changing its coefficients in function of some auxiliary variables, under real time operation conditions. This can lead to instabilities in the canal pool control system. These problems of adaptive controllers have been extensively reported in the literature. Guaranteeing their stability is a difficult task, which usually implies some Lyapunov analysis.

This paper is organized as follows. A mathematical model of a main irrigation canal is obtained in Section 2. An introduction to fractional order operators and controllers is presented in Section 3. A method to design robust PID controllers for main irrigation canals is proposed in Section 4. Section 5 generalizes the previous method to design robust fractional controllers. Section 6 describes the application of this new method to a particular main irrigation canal and its simulated results are compared with the results obtained from the standard PID controller of Section 4. Section 7 reports some experimental results in a canal prototype, and finally some conclusions are drawn in Section 8.

## 2. Main irrigation canal model for control

A typical main irrigation canal consists of several pools separated by gates that are used for regulating the water distribution from one pool to the next. Fig. 1 shows a scheme of a main irrigation canal with gates.

In automatically regulated canals, the controlled variables are the water levels ($y_i(t)$), the manipulated variables are the gate positions ($u_i(t)$), and the fundamental perturbation variables are the unknown offtake discharges ($q_i(t)$). If the water levels are measured near the end of the pool, the control system is called distant downstream control. Downstream control is considered to be superior to upstream control because it increases the efficiency of water use and improves the reliability and flexibility of the system (Liu, Feyen, & Berlamont, 1995). The choice between downstream and upstream control is to a certain extent dictated by the design of the canal, and it may not be

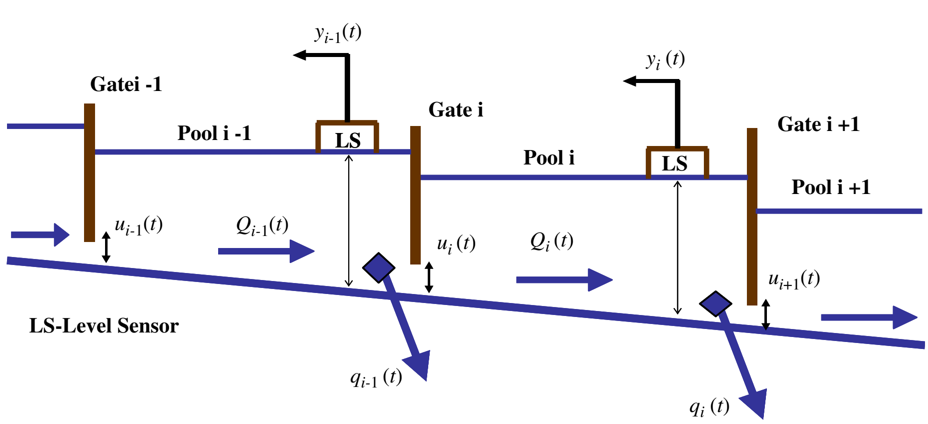


Fig. 1. Scheme of a main irrigation canal with gates.