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CLASSIFICATION OF CANAL CONTROL ALGORITHMS

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Abstract

Different control algorithms have been developed and applied in the world for the regulation of irrigation canals. Each of them can be characterized according to several criterias among which: the considered variables, the logic of control, and the design technique. The following text presents definitions of these terms, and a classification of the algorithms detailed in the literature.

1. Introduction

A control system is an elementary system (algorithm + hardware) in charge of operating canal cross structures, based on information from the canal system. This information may include measured variables, operating conditions (e.g. predicted withdrawals) and objectives (e.g. hydraulic targets). Boundaries of the control system are outputs of the sensors placed on the canal system, and inputs of the actuators controlling the cross structures. The following text presents definitions and a classification of canal control algorithms developed or used in the world. Hardware aspects will be presented in a separate paper.

2. Definitions

Several criterias can be used to define control algorithms. The three essential ones are: considered variables, logic of control, and design technique.

2.1. Considered variables

Variable location is given in reference to a pool and not to a structure (e.g. upstream end, intermediate or downstream end of a pool). This avoids confusion in the case of a multivariable control algorithm, where a variable can be controlled

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by both upstream and downstream structures. The location of controlled variables in a pool is indicative of hydraulic behavior (e.g. available storage volume) and civil engineering constraints (e.g. bank slopes). Three types of variables are considered in control algorithms:

Controlled variables are target variables controlled by the control algorithm. Examples are water level at the upstream end of a pool (Yu), water level at the downstream end of a pool (Yd), flow rate at a structure (Q), volume of water in a pool (V), and weighted water level (e.g. α Yu + β Yd). Controlled variables are not necessarily directly measurable.

Measured variables, also called inputs of the control algorithm, are the variables measured on the canal system. Examples are water level at the upstream end of a pool (Yu), water level at the downstream end of a pool (Yd), water level at an intermediate point of a pool (Yin), flow rate at a structure (Q), and setting of a structure (G).

Control action variables, also called outputs of the control algorithm, are variables issued from the control algorithm and supplied to the cross structures' actuators. They are either gate positions (G) or flow rates (Q). In this latter case, another algorithm transforms the flow rate into a gate position. This algorithm is important from hydraulic and control points of view, and is considered as a separate control algorithm.

Remark: **I/O structure** is the number of inputs and outputs considered by the control algorithm. A control algorithm is said nImO when it has n inputs (measured variables) and m outputs (control action variables). Special names are given in specific cases: SISO (Single Input, Single Output, if $n = m = 1$), MISO (Multiple Inputs, Single Output, if $n > 1$ and $m = 1$), and MIMO (Multiple Inputs, Multiple Outputs, if n and $m > 1$).

2.2. Logic of control

The logic of control refers to the type and direction of the links between controlled variables and control action variables.

Type: the control algorithm uses either feedback control (FB, also called closed-loop control), feedforward control (FF, also called open-loop control) or a combination (FB + FF). In a feedback control algorithm, the controlled variables are measured, or directly obtained from measurements. Any deviation from the targets is fed back into the control algorithm in order to produce a corrective action. In a feedforward control algorithm, the control action variables are computed from targeted variables, perturbation estimations and process modelisation. Feedforward control usually improves control performance when few unknown perturbations occur in the canal system.

Direction: a structure can be operated to control a variable located further downstream, which is called downstream control. All variables (discharge, level or volume) can be controlled with downstream control. A structure can also be operated to control a variable located further upstream, which is called upstream control. Only levels or volumes can be controlled with upstream control, when flow conditions are subcritical and under the limitations of the backwater effects.

2.3. Design technique

The design technique is the algorithm or methodology used within the control algorithm in order to generate the control action variables, from the measured variables.

Main design techniques examples are three position, heuristic, PID, pole placement, predictive control, optimal control, fuzzy control, neural network, backward simulation, linear optimization, and non-linear optimization.

Additional components: a main technique can benefit from additional components that may improve control algorithm performance by accounting for canal system features. Examples are filter, decoupler, observer, Smith predictor, and autoadaptative tuning.

3. Classification

Canal control algorithms detailed in the literature are classified in Table 1. They are listed according to their main design technique (e.g. heuristic or PID). Complete references can be found in Zimbelman 1987, Goussard 1993 or Malaterre 1994.

4. References

Goussard J. 1993. Automation of canal irrigation systems. International Commission of Irrigation and Drainage, Working Group on Construction, Rehabilitation and Modernisation of Irrigation Project, ICID, 103 p.

Malaterre P.O. 1994. Modélisation, analyse et commande optimale LQR d'un canal d'irrigation. Ph.D., ENGREF - Cemagref - LAAS CNRS, 255 references, 200 p.

Zimbelman D.D. 1987. Planning, operation, rehabilitation and automation of irrigation water delivery systems. Proceedings of a symposium ASCE, Portland, Oregon, USA, 28-30 July 1987, 377 p.

Table 1. Classification of canal control algorithms.

IDENTIFICATION		CHARACTERIZATION							APPLICATIONS OR TESTS
Name	Developer	Considered variables			I/O	Logic of control		Design Technique	
		controlled	measured	ctrl. act.	Struct.	Type	Direct.		
DACL	USWC Lab	y_{dn}	y_{dn}	G	SISO	FB	up	3 position	
LittleMan	USBR and others	y_{up} or $_{dn}$	y_{up} or $_{dn}$	G	SISO	FB	dn or up	3 position	Several in USA
CARDD	Burt & Parrish	y_{dn}	3-5 y_{in}	G	3-5ISO	FB	dn	Heuristic	CalPoly scale canal
RTUQ	Rogers	Q	y_{up} y_{dn} & G	G	3ISO	FB	dn	Heuristic	Dolores Project
	Zimbelman	y_{dn}	y_{dn}	G	SISO	FB	dn	Heuristic	Model
	CARA	Q & y	Q & y	Q	SISO	FB + FF	dn	Heuristic + PID	Several in France
	Najim	y	y	Q	?	FB + FF		Variable structure	
AMIL, AVIS, AVIO	GEC Alsthom	y_{up} or $_{dn}$	y_{dn} or $_{up}$	G	SISO	FB	up or dn	P	Several countries
Danaïdean system		y_{dn}	y_{dn}	G	SISO	FB	up	P	Several in USA
Mixed Gates	GEC Alsthom	$f(y_{up}, y_{dn})$	y_{up} & y_{dn}	G	2ISO	FB	up + dn	P	Several countries
BIVAL	Sogreah	$f(y_{up}, y_{dn})$	y_{up} & y_{dn}	G	2ISO	FB	dn	PI	Mali, Mexico, etc.
Dynamic Regulation	SCP - Gersar	V	y_{up} y_{dn} & G	Q	3ISO	FB + FF	dn	PI	France, Marocco
	IMTA - Cemagref	y_{dn}	y_{dn}	Q	SISO	FB + FF	dn	PI	Begonia (Mexico)
	UMA Engineering	y_{dn}	y_{dn}	G	SISO	FB	up	PI	Imperial Valley
ELFLO / P+PR	Buyalski, Serfozo	y_{dn}	y_{dn} & G	G	2ISO	FB	dn / up	PI + filter	Several in USA
	Sogreah	y_{dn}	y_{dn}	G	SISO	FB + FF	dn	PI + filter	Kirkuk (Iraq)
	IMTA - Cemagref	y_{dn}	Q_{dn} y_{up} y_{dn}	Q_{up}	3ISO	FB + FF	dn	PID + pole placement	Yaqui (Mexico)
ELFLO + Decoupler	Schuurmans	y_{dn}	y_{dn} & G	G	2-3ISO	FB	dn	PI + filter + decoupler	CalPoly scale canal
PIR	SCP - Gersar	y_{dn}	y_{dn}	Q	2ISO	FB	dn	PI + Smith predictor	France (SCP)

	CACG Cemagref	Q_{dn}	Q_{dn} & Q_{in}	Q_{up}	3ISO	FB + FF	dn	Pole placement	Several in France
CARAMBA	De Leon	Q_{dn}	Q_{dn}	Q_{up}	SISO	FB + FF	dn	Pole placement	Model
	Sawadogo	Q_{dn}	Q_{dn}	Q_{up}	SISO	FB + FF	dn	GPC	Non linear model
	Rodellar, Gomez	Q_{dn}	Q_{dn}	Q_{up}	SISO	FB	dn	Predictive control	Non linear model
	Zagona & Clough	Q & y	Q & y	G	MIMO	FB + FF	dn	Predictive control	Model
	Corriga	y	y_{up} & y_{dn}	G	MIMO	FB	up + dn	LQR + observer	Non linear model
	Davis U.	Q & y	y_{up} & y_{dn}	Q & G	MIMO	FB	up + dn	LQR + observer	Non linear model
PILOTE	Cemagref	Q & y	y_{up} y_{dn} & Q	Q_{up} & G	MIMO	FB + FF	up + dn	LQR + observer	Non linear model
	Reddy	Q & y	y_{up} & y_{dn}	G	MIMO	FB	up + dn	LQR + observer	Non linear model
FKBC	BRL - Gersar	Q_{dn}	Q_{dn}	Q_{up}	SISO	FB + FF	dn	Fuzzy control	T2 (Morocco)
ANN	Schaalje & Manz	y	y	G	MIMO	FB	up + dn	Neural network	Model
	Toudeft	Q_{dn}	Q_{dn}	Q_{up}	SISO	FB	dn	Neural network	Model
ACS	CAP, USBR	Q & y	-	G	MIMO	FF	dn	Model inversion	Central Arizona P.
CLIS	Liu	Q & y_{dn}	y	G	MIMO	FB + FF	dn	Model inversion	Non linear model
Controlled Volumes	CSWP	V	y or Q	G	MIMO	FB + FF	dn	Model inversion	Calif. Aqueduct
Gate Stroking	Wylie, Falvey	Q & y_{dn}	-	G	MIMO	FF	dn	Model inversion	CAP (USA)
	O'Laughlin	Q & y_{dn}	-	Q & G	MIMO	FF	dn	Model inversion	Scale Model
SIMBAK	Chevereau	Q_{dn}	-	Q_{up}	SISO	FF	dn	Model inversion	Non linear model
DYN^2	Filipovic	V	y	Q	MIMO	FB + FF	dn	Linear optimization	Yugoslavia
	Sabet	V	-	Q	MIMO	FF	dn	Linear optimization	CSWP
	Cemagref	Q & y	-	Q & G	MIMO	FF	dn	Non-linear optimisation	Wateringues
NLP	Lin & Manz	Q & y	-	Q & G	MIMO	FF	dn	Non-linear optimisation	Model
	Tomicic	Q & y	-	Q & y	MIMO	FF	dn	Non-linear optimisation	Model