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CANAL CONTROL ALGORITHMS CURRENTLY IN USE

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Abstract

Many canal control methods and algorithms have been developed, but only some of them are being used on operating canal projects. As a part of the ASCE task committee on *Canal Automation Algorithms*, this paper discusses field application of automatic control algorithms. Based on available data, brief information on algorithm implementation is presented.

Introduction

Canal automation has been evolving for several decades now, to the point where most new canal designs and canal modernization projects include some level of automation. Numerous canal control algorithms have been developed, but how many of these algorithms have been implemented in the field? The practical implications, successes, and failures of control algorithms may be more important than theoretical performance. Canal control algorithms currently in use are summarized in the sections below, categorized as implicit algorithms in self-regulating gates, local automatic feedback controllers, and supervisory control algorithms. Many of these algorithms are described in the references (Buyalski et al 1991, Goussard 1993, and Zimbelman 1987).

Implicit Algorithms Integrated in Self-regulating Gate Design

Although they do not execute an algorithm in the customary sense, these hydro-mechanical control devices are used successfully on many canal projects:

- ***Constant upstream level gates (AMIL gates)*** - The first operational AMIL gates were installed in Algeria (Oued Rhiou area) in 1937 for automatic upstream control

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of a main canal (10 m^3/s max.). Most of those gates are still working. In 1950, nearly 1000 such gates had been installed, mainly in North Africa. Among recent significant references are the North Jazirah 1 & 2 projects, Iraq (1987-1989, 30 m^3/s max., 30 gates) and the Selangor project, Malaysia (1989, 20 m^3/s max., three gates). AMIL gates also are used to control levels in drainage systems (Disney World, Florida).

• ***Constant downstream level gates (AVIS and AVIO gates)*** - This gate type was developed and first applied in the late 1940's (over 400 gates installed before 1951, mainly in France and Algeria). Hundreds have been installed throughout the world since then, for downstream control of level-top canals. A recent reference (1989) is the Sidorejo area of the Kedung Ombo project, Indonesia, with four AVIS gates on the main canal (9.5 m^3/s max.) and four AVIO gates on turnouts to secondary canals. Significant also is the fact that the flow (40 m^3/s max.) at the head of the Canal de Provence system, France, is automatically controlled according to downstream demand through two AVIS gates in parallel.

• ***Mixed gates*** - Mixed gates are used for related level control of reservoir pools, which is their basic operating mode, and for mixed control. One of the earliest applications (1955-1961) has been the control of the reservoir pools forming the two main branches of the Bas-Rhône Canal in France (respectively 61.5 and 13.5 m^3/s) through 7 mixed gates, for the purpose of compensating for the mismatch between the pumped head supply and the lateral on-demand deliveries. The most recent reference (1993) is Canal T2, ORMVA Haouz, Morocco, with two mixed gates controlling a 20 km reservoir reach linking an upstream feeder section (53 km, 12 m^3/s max.) under upstream control to a downstream section of 20 km under downstream control.

• ***Danaidean system*** - Some applications of this system to canal control can be found in several European, Asian, and American countries. For example, in the USA it has been applied to upstream level control with maximum flows ranging from 0.5 m^3/s (Tranquility I.D., California) to 30 m^3/s (Imperial I.D., California). Though simple and efficient, the system has not been widely used because of the bulky additional structures required to provide buoyant counterweights.

Local Automatic Feedback Controllers

a. **Three-position controllers.**

• ***Little-Man*** - The first automatic gate controller in the USA was an electromechanical, three-position (floating, set-operate-time, set-rest-time) controller called the Little-Man, installed in 1952 by the Bureau of Reclamation (USBR). Little-Man controllers have been used to maintain a target water level adjacent to (either upstream or downstream from) the controlled gate. They are most effective in applications with a single structure or a few isolated structures, because instability can develop when three-position controllers are installed on a series of check structures. Among numerous installations are Friant-Kern Canal in California (243 km, 113 m^3/s max., 13 check structures) and the Columbia Basin project in Washington (several branch canals with a total of some 50 pools extending over 385 km, with maximum flows ranging from 16 to 144 m^3/s). More recently, the Little-Man algorithm has been programmed into microprocessor canal controllers on projects such as Government Highline Canal in Colorado.

• ***Colvin*** - The Colvin controller adds a rate control mode to the three-position mode to improve performance. Developed and improved by the USBR from 1971 to 1980, Colvin controllers have been applied to upstream control of diversion dam gates (North Poudre supply canal diversion dam, Colorado, and San Juan-Chama Project, New Mexico) and to downstream control of turnout or outlet gates (Loveland turnout from Hansen Feeder Canal, Colorado, and Flatiron afterbay outlet, Colorado).

b. **PI and PID controllers.**

A number of analog and microprocessor-based controllers integrating PI or PID (Proportional-Integral-Derivative) algorithms have been developed and applied for the last two decades. They differ not only in hardware but also in their internal control logic and in their application.

Control of a distant downstream level:

• ***ELFLO*** - In the early 1970's, the USBR developed the analog controller EL-FLO plus Reset from the results of a previous research program on a controller suitable for distant downstream level control (HyFLO, then EL-FLO). ELFLO (Electronic Filter Level Offset) controllers were first installed on Corning Canal, California (1974, 14 m^3/s max., 34 km, 12 check structures) and on Coalinga Canal, California (three check structures). Automatic control was implemented on these projects because flow changes were straining the capabilities of manual gate control. Control performance is good at low flows but degrades as canal flow approaches design capacity; at high flows, canal operators switch controllers into an upstream mode. In recent years, microprocessor PID controllers have replaced ELFLO in USBR applications.

• ***Sogreah PID*** - This PID controller by Sogreah, France, was installed in the 1970's to control the level at the downstream end of the 37 km head reach (278 m^3/s max.) of the Kirkuk-Adhaim main canal in Iraq; similar controllers are currently being installed on the Cupatitzio-Tepalcatepec Project in Mexico (five check structures on a secondary canal of the right bank system and a dam outlet to the left bank system).

• ***IMTA PID*** - PI and PID controllers have been developed by IMTA, Mexico, in collaboration with CEMAGREF, France, and recently installed on Mexican projects under modernization, e.g. La Begoña main canal (20 km, 10 m^3/s, five gate structures), and the Canal Alto of Rio Yadui I.D. (120 km, 110 m^3/s, 15 structures).

Control of a constant level close upstream or downstream:

• ***P+PR*** - The P+PR (Proportional plus Proportional Reset) algorithm is essentially the same as ELFLO, except applied in an upstream (supply-oriented) mode. P+PR has been implemented at the Yuma Desalting Plant Bypass Drain Canal (Arizona), Umatilla Basin (Washington), Closed Basin Canal (Colorado), and Dolores Project (Colorado). In each of these applications, controllers are installed at several canal check structures in series to route flow changes downstream through the canal while maintaining water level upstream from each check.

• ***UMA*** - UMA Engineering, Canada, in collaboration with Armtec, has developed a system combining drop-leaf gates and programmable local controllers

(Modicon or TeleSafe). This system is installed on the St. Mary River I.D. main canal, Alberta, Canada (280 km, 91 m^3/s max., upstream level control at check structures, indirect flow control via downstream level control at outlet gates) and at the South San Joaquin I.D. main canal, California (1989, 40 km, 26 m^3/s max., upstream control of 10 check structures, flow control through downstream level control for two check structures).

- ***Related level control*** - To our knowledge, the only controllers using this logic are those installed in the 1970's by Sogreah, France, to control the two reservoir-reaches (22 km each, 232 and 130 m^3/s respectively) of the Kirkuk-Adhaim main canal in Iraq, to maintain a constant difference between the level just upstream from each regulator and the level at the far end of the pool downstream from the same regulator.
- ***Constant volume (BIVAL) control*** - This logic, developed by Sogreah, has been applied to two reaches (62 km each, 75 m^3/s) of the Sahel canal in the Fala de Modolo system in Mali, since 1983. As only infrequent gate adjustments were required, the concerned regulators are operated manually from level readings and using charts. An automated BIVAL control system is currently under implementation on the right bank of the Cupatitzio-Tepalcatepec Project, Mexico.
- ***PIR control*** - The PIR algorithm has been developed by Société du Canal de Provence in 1992-1993 and has been satisfactorily controlling a branch of the Canal de Provence system since 1994. For this first operational application, the software has been integrated into the Dynamic Regulation system and no specific hardware has yet been developed or selected for a possible canalside PIR controller.

c. **Heuristic controllers.**

- ***RTUQ*** - The RTUQ (Remote Terminal Unit flow control) algorithm was developed by USBR in 1992. The algorithm uses a feedback loop to maintain a target flow through a gated check structure. RTUQ is being used at the Dolores Project, Colorado (125 km, 11 m^3/s max., 60 check gate structures) as part of a supervisory control system. The algorithm has performed well when all data is in order. Enhancements have been added to improve stability when downstream water levels are in the transition zone between free gate flow and submerged gate flow.

<u>Supervisory (or Centralized) Control Algorithms</u>

- ***Dynamic Regulation*** - Dynamic Regulation was developed by Société du Canal de Provence, France, for application on the Canal de Provence system (1971, 105 km of main and branch canals, 130 km of pressure pipes and tunnels, 40 m^3/s max., 33 regulating gates, 24 emergency gates, four pumping stations, and two in-line hydro plants). The system has shown a high degree of efficiency and reliability. Dynamic Regulation also has been successfully applied to complex systems in Greece (Athens water supply), Macedonian Republic (Stretzevo Irrigation Project), and Morocco (Rocade Canal, 127 km, 20 m^3/s, seven check structures, two main turnouts, 15 RTU's).
- ***ACS*** - ACS (Aqueduct Control Software) was developed by USBR in the 1980's to control the Central Arizona Project canal system (540 km of open

canals, inverted siphons, and tunnels, 85 m^3/s max., 36 check structures, 14 in-line pumping plants). The project is demand-oriented, delivering water for irrigation and municipal use without any wasteways to spill excess water. ACS solves canal hydraulics using model inversion (backwards simulation) to control water volumes throughout the canal system while minimizing pump starts. ACS executes on a master station computer and sends control schedules to microprocessor RTU equipment at pumping plants, check structures, and turnouts.

• ***Controlled Volume*** - This control method was developed in the 1970's for the California Aqueduct (710 km, 290 m^3/s max., 242 turnouts, and some 90 aqueduct pools with tunnels, siphons, 66 gated check structures, and 27 pumping and power plants). The centralized algorithm controls pool volumes to satisfy scheduled water demand while minimizing pumping power costs and avoiding overloading of the power supply network. Although the system was designed to respond to delivery changes on relatively short notice, farmers (30% of the yearly deliveries) reproach the system some lack of flexibility.

• ***CACG*** - This method was developed from the mid-1960's and continuously improved since, by Compagnie d'Aménagement des Coteaux de Gascongne, France, for central management of flows and reservoirs in a system of rivers. The main reference is the Neste system, France, for which the method was devised (17 rivers totaling 1300 km, four in-line dams, and a 29 km, 14 m^3/s feeder canal). The objectives of the project--satisfying user demand, maintaining minimum flows required for water quality, and improving the conveyance efficiency (now about 90%) by reducing operational losses--are considered to be fully met.

• ***FKBC (Fuzzy Knowledge-Based Controller)*** - This controller has been developed very recently by BRL-Ingénierie (a division of Compagnie Nationale d'Aménagement de la Région du Bas-Rhône et du Languedoc, France). A first FKBC was installed and put into operation at the beginning of 1995, as a part of the supervisory control system of Canal T2 in Morocco (see Mixed Gates above). FKBC determines the optimal flow setpoint for the two radial head gates, based on demand forecasts, current system-wide status, a rule base, and a database.

Conclusions

Although this paper summarizes canal control algorithm implementation, it is not an all-inclusive compilation. The authors welcome additional information on canal projects where control algorithms currently are being used.

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