Implementation of Canal Automation in Central Arizona

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ABSTRACT

The automation of irrigation distribution canals in central Arizona promises to improve water-delivery service to farmers, reduce operating cost, and improve distribution efficiency (i.e. reduce unaccounted for losses). Testing and implementation of canal automation is being carries out with two irrigation projects in Central Arizona, the Salif River Project (SRP) and the Maricopa Stanfield Irrigation and Drainage District initiated with Automata, Inc., a manufacturer of electronic sensing and control systems, for developing a canal automation product line. Implementation of canal automation within these two projects will demonstrate the capabilities and limitations of this technology. The cooperation with Automata will put this technology (software and hardware) into the marketplace and allow more straightforward application to other irrigation districts.

INTRODUCTION

Declining groundwater levels in the Central Arizona Senoran Desert prompted the State of Arizona to restrict groundwater pumping and prompted irrigated agriculture districts and the U.S. Bureau of Reclamation (USBR) to construct the Central Arizona Project (CAP), which transports Colorado River water to central Arizona. Most irrigation groundwater. The high cost of pumping groundwater and transporting Colorado River water to Central Arizona has increased the need for more efficient use of that water. Improved measurement and control, thus, are a high priority in most central Arizona districts. Additionally, the USBR requires irrigation districts to develop and implement water conservation plans, including improved operation (e.g. canal automation).

Research on canal automation has increased significantly over the past decade. Malaterre (1995) cited 98 papers on canal regulation, with all but about 20 published within the last 10 years. Most of the earlier articles describe mechanical, analog-electrical, or ad-hoc control methods. The most recent developments in canal automation are based on digital control, which offers many advantages over traditional analog control, including convenient interface to personal computers. Any centralized control scheme essentially requires that the signals be processed digitally.

Most of the papers on canal automation deal only with closed-loop control logic, without anticipation for known demand changes. While closed-loop control is technically complex component, by itself if is not sufficient for automation of most canals. Further, many of the failures in canal automation have resulted from incompatibility of system components (e.g. MSIDD in Clemmens et al 1994). Many districts have developed their own supervisory (manual0remote) control systems (e.g. SRP in Shipley and Juetten 1970), or use commercial systems based on programmable logic controllers (PLCs). Such systems typically do not have the capabilities to fully implement modern, digital control methods. Controllers with higher-level language programming are usually needed. Further, cooperation with companies who develop, manufacture and distribute data collection and control equipment can promote the adoption of this technology by reducing the need to conduct extensive research for every canal automation project. The purpose of this paper is to describe activities currently ongoing in central Arizona on the implementation of canal automation with two irrigation districts and on the development of an off-the-shelf canal automation product.

CANAL AUTOMATION LOGIC

Canal automation must fit within the overall operating procedure of the district, including the water ordering system, canal operations, system constraints, delivery gate control, demand flexibility allowed, etc. Different automation features are needed for different parts of the system. This may mean a combination of local-control, central-control, and intermediated, distributed-control functions. For local control, information gathered at a given site (e.g., local water level) is used to determine a control action at that site (e.g., gate movement). A Remote Terminal Unit (RTU) performs the signal processing and control functions, locally, for an individual site. For central control, information from individual RTUs are communicated to a control center. The control center processes this multi-site data and sends control signals back to the individual RTUs. For distributed control, information from on or more RTUs is passed another RTU, where the necessary control actions are determined, without going to the control center. A control center should always be included in systems with local or distributed control so that operators can observe system behavior and collect data on long-term performance.

Control system logic is more complicated than the simple discussion above implies. Most irrigation delivery canals have a significant slope and little extra capacity for water storage. Once water flows into the canal, it will flow out of the canal at some point downstream at a later time. The time delay for flow changes to travel though the canal and the behavior of the resulting waves make the automation of canals more difficult than one would expect. Also, gate hydraulics and pool dynamic response are sometimes hard to separate, as are the interactions between neighboring pools. These problems can be minimized by separating the control of gates from the control of pool dynamics. This is done by using a <u>flow control function</u> for each check structure, which sets the gate position(s), and <u>a pool level or volume control function,</u> which determines the flow rate setting for each check (e.g., either locally or centrally).

CONTROLLER DESIGN

For closed-loop controller design, we use the approximate canal flow model developed by Schuurmans et al (1995). This model provides a simple framework for developing canal automation algorithms from two-canal pool properties; the wave travel time for any segment of a canal pool flowing at normal depth, and the water surface area of the backwater upstream from each control structure. When backwater affects the entire length of a pool, the travel times through that pool are insignificant, but the flow is affected by reflection waves. Instabilities caused by these waves can be eliminated by introducing a low-pass filter, a mathematical smoothing procedure (e.g., as in ELFLO, Rogers et al 1995). We also use Schuurmans' (1996) state-feedback approach to controller design, where prior control actions are added to the state vector to account for time delays. The method can produce controllers ranging from optimal control to global tuning of local PI controllers, including Deltour's (1992) PIR (PI with delay) control.

For open-loop control, we use one of several methods including a simple time delay (e.g., Schuurmans et al 1995) and the gate-stroking method of Bautista et al (1997). This open-loop control is implemented simultaneously with but independently from the closed-loop control.

MARICOPA STANFIELD IRRIGATION AND DRAINAGE DISTRICT

The 35,000 ha Maricopa Stanfield Irrigation and Drainage District (MSIDD) is located in central Arizona and receives water from the Central Arizona Project and from groundwater. The system was designed so that all canal check structures (cross-regulators) could be controlled remotely from a personal computer based supervisory control center. However, the district began delivering water through manual operation in 1987. Installation of canal gate remote control equipment, including motorized gates, RTUs and radio communication was not completed until 1989. The remote supervisory control system, including significant modification by the district, was completed and on line in 1991. An option was provided for automatic downstream feedback control. The scheme was tested, unsuccessfully, and abandoned (Clemmens et al 1994).

The district's WM canal (2.7 m3/s capacity) was selected to conduct canal automation research. Data collected during 1992 provided a good test case for the evaluation of closed-loop downstream-control algorithms (Clemmens et al 1994). The location and small size of this canal allowed convenient testing of controllers without disturbing other parts of the canal systems. This canal was subsequently used to develop test cases by the ASCE Task Committee on Canal Automation Algorithms (Kacerek et al 1995).

Simulation studies on the WM canal were conducted with several different closed-loop controllers and the CANAL_CAD unsteady-flow canal-automation simulation program (Holly and Parrish 1992). In general, flow rate control provided better performance than gate position control, even when flow rates were inexactly known. Also on this steep canal, accumulating requested control actions in the upstream direction provided better overall control. Third including knowledge of previous flow changes with prediction of their effects (i.e. modeling casual response delay) also greatly improved control.

Field-testing on MSIDD's WM canal began in March 1995, with the assistance of researchers from Delft University of Technology. The MATLAB mathematical software package (MATLAB 1993), the unsteady simulation model MODIS (Schuurmans 1995), and MOBLAB (Schuurmans 1994), a program that links MATLAB with MODIS, were used to develop and test various canal controllers. Initial tests of open-loop response verified the reasonableness of the linear model used to develop controller constants (Ellerbeck 1995). The supervisory control software used by MSIDD could not handle the automatic control functions simultaneously with their manual supervisory operations. Therefore, the automatic control function was programmed into a second generation of their software (Taylor 1995). The state-feedback control logic was programmed into this software and operated from a separate computer but through the same radio link as MSIDD's supervisory control system. Initial closed-loop tests were somewhat successful (Liem 1995). A typical test would be to start with a reasonably stable canal and make a step change in flow, for example turning off a groundwater well discharging into the canal. The control system brought the water levels back to the set points reasonable well, but encountered the following problems. First, the gates did not have reliable position sensors, making the debugging of control system problems almost impossible. Second, due to the gate width, the minimum gate movement allowed by the MSIDD control system was too large to produce effective control (i.e., it caused oscillations). Flow rate control was performed centrally for there tests, but was only moderately effective. A shorter time period for local-rate control would have been better.

In late 1995, a Cooperative Research and Development Agreement (CRADA) was reached with Automata, Inc. to develop a canal automation product line—plug and play canal automation—including an entire package from the gate motor controllers to the control center software. MSIDD's WM canal was chosen as the site for development of this product line. A new gate position sensor was developed and installed at each gate for the WM canal, considering the need to measure and control gates precisely (e.g., within 1 mm). Automata's new generations RTU was chosen for use on this canal. New controller boards were built to operate the gate motors from the new RTUs. Automata obtained a multi state license for radio frequency, to aid in more rapid application of the technology, and provided radios for this project. The RTUs were purchased by the Water Resources Laboratory of USBR, with funding from USBR's Lower-Colorado Region, Office of Water Conservation. This equipment will be installed in late 1996.

SALT RIVER PROJECT

The Salt River Project (SRP) was established in 1903 and provides water and power to agricultural and urban within the Salt River Valley in central Arizona. SRP has a 100,000 ha service area and operates a series of seven multipurpose reservoirs on the Salt and Verde River system. A remote, manual supervisory control system was first implemented on SRP's main canals in the mid 1960's, which was replaced in 1991 with a new supervisory control center. Over the last 3 decades, a significant shift from agricultural to urban water use has taken place. In addition, SRP receives and delivers CAP water to urban and other customers through their distribution network. This has created new demands on canal operators, e.g. water transfer agreements that have diverted their attention from normal canal operations. These new demands have prompted SRP's water operations staff to investigate the potential of canal automation to reduce the increasing burden on the operating staff. A pilot project was initiated in 1996 to study automation on the upper reach of Arizona Canal (43 m3/s capacity).

SRP's surface water supply comes from its reservoirs to the Granite Reef Diversion Dam, where flow enters the Arizona and South canals on opposite sides of the river. The Upper Arizona Canal is 30.6 Km long and has four pools. At that point, flow is split roughly in half to the Grand and lower Arizona canals. The two upstream pools are long and steep relative to the two lower pools. This canal was originally an earthen canal, but has since been lined with shotcrete (a concrete that is sprayed on over the existing earth surface). There is some question whether Granite Reef Reservoir has the capacity to allow automatic downstream control. The pilot project will help to answer that question.

The objective of Phase I of this canal automation pilot project is to test automatic control with an unsteady-flow simulation model. Phase I consists of 5 steps: 1) determine the dynamic response of each pool and verify relevant hydraulic relationships, 2) modify the unsteady-flow simulation model to incorporate the user-written control procedures, 3) select the controller and develop the controller constants, 4) test the control algorithm with the unsteady-flow simulation model, and 5) analysis and report.

The unsteady-flow simulation package, Mike 11 (DHI 1992) was chosen to simulate unsteady flow for the Arizona Canal, since SRP had the model set up for simulation on their entire canal network. The original Mike 11 package allows gate setting and off take changes to be determined as a function of time from data input tables. Closed-loop control requires that gate settings be determined in real time from the observed water levels. A special user-interface was developed by DHI to allow us to write the closed-loop control functions to adjust gates from the Mike-11 computed water levels.

In the spring of 1996, several open-loop tests were performed when the district made flow changes in the Arizona canal of about 10%. These tests verified that Mike 11 was properly calibrated for this portion of the canal. The response in water level of each pool to a step change in inflow was determined by Mike 11. Each pool was modeled independently over a range of low rates and downstream boundary was a constant flow rate, provided by a user-written routine. This water level response was used to determine delay times, backwater surface area and reflection wave frequency for each pool, which will be used to develop a controller constant. SRP water masters have provided seven scenarios for testing these control algorithms. This project is scheduled for completion in January 1997. Further details can be found in Clemmens et al (1997).

Phase II of the project will involve SRP’s supervisory control system so that it can handle automatic control and demonstration of the control system to water masters to gain their understanding and acceptance of the system. In Phase III, the control system would be tested on the actual canal in real time over an irrigation season.