

*Abstract*

In 1995, Automata, Inc., a private manufacturer of agricultural sensing and control equipment, and the U.S. Water Conservation Laboratory (USDA-Agricultural Research Service) joined into a Cooperative Research and Development Agreement (CRADA) to develop a low-cost, integrated package for canal automation, including hardware and software, that would essentially make canal automation a plug-and-play system. The low cost of this integrated package is particularly applicable to smaller canals. *This* paper is a progress report on the on-going development and field testing of *this* equipment and control methodology.

*Introduction*

Modern, high-efficiency irrigation systems require a flexible and stable water supply. Open-channel water-delivery distribution networks are typically not capable of *this* high level of service. Stable flows can be achieved when little flexibility is allowed since canal operators can force canals flows to be relatively steady. Allowing more flexibility increases the amount of unsteady flow and can lead to poor delivery performance. Most canal systems operate with manual upstream control. A constant water level at upstream from each check structure is maintained to keep delivery flow rates constant. Improving the flexibility and control of these canals is usually accomplished by increasing labor (e.g., 24 hour shifts), by allowing significant canal spills, or by restricting water-user flexibility.

A number of methods for the control of irrigation canals have been proposed in the literature. These are summarized by Malaterre, et al. (1998). Very few automatic control systems have actually been used in practice (Rogers and Goussard 1998). In this paper, canal automatic control refers to control of canal gates without human intervention. Most of the automatic control systems in use deal with only one limited operational function (e.g. only feedback control) and may be difficult to integrate with other delivery system operations. A number of more modern downstream control algorithms have been proposed, but none have been adequately tested in the field. Research is currently underway to test the application of these methods, and to integrate them into the overall operation of the project (e.g. water ordering, accounting, etc)

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Because of the substantial investment in hardware and engineering analysis, canal automation is currently only practical for large main canals. Most of the canal automation systems currently in use required extensive research and development for application to one particular canal. In addition, canal automation components are often not routine, off-the-shelf items and compatibility between available components makes their application difficult. Recent advances in low-cost instrumentation and advances in canal automation research may make application of canal automation more straightforward, less expensive, and thus practical on smaller canals. A Cooperative Research and Development Agreement between the Agricultural Research Service (ARS) and AUTOMATA, Inc., was established for the purpose of developing off-the-shelf hardware and software for canal automation. The objective of this research and development project is to develop a canal automation product that includes all the hardware and software components needed to apply remote, centralized, computerized control. This product should be applicable to a wide variety of conditions and can be applied to a given canal without a major research effort.

### USWCL Canal Automation System

Many canals are not physically capable of handling large unscheduled changes in demand (Strelkoff, et al. 1998). This limitation is imposed by the physical system and is not related to the limitations of an automatic control system. Thus, automatic downstream water level control systems (whether local or global) will never be able to solve all canal operational control problems. Reservoirs or the routing of major flow changes will still be required. Automatic routing of scheduled flow changes has not been entirely successful in practice either--particularly due to the inability of these methods to handle unanticipated changes. New routing methods based on volume have been proposed that make these methods more practical (Bautista and Clemmens, 1998). More importantly, flow routing (open-loop, feedforward control) is never perfect and errors in flow will propagate to the downstream end unless downstream water level feedback is also included. Combining downstream water level feedback with feedforward routing of major flow changes is essential for the practical application of canal automation.

It has also been argued that flow control at gate structures provides much better control than control of gate positions. This is well known in the process control industry, where for a series of local feedback controllers (as are a series of local canal pool controllers), flow rather than valve position control is used to limit the interactions. If the feedback and feedforward controllers each provide a flow controller with changes in flow rate at each check structure, the combination of these into a common control scheme is vastly simplified. For check structures with multiple gates, separate logic can be used to decide which gate or gates to move, rather than moving all gates identically, which in many cases is operationally unacceptable. In this way, the hydraulics of the gates is separated from the hydraulics of the canal pools -- each are treated independently.

The proposed control system, shown in Figure 1, has three main components;

- 1) downstream water-level feedback control,
- 2) open-loop feedforward routing of scheduled or measured offtake flow changes, and
- 3) flow control

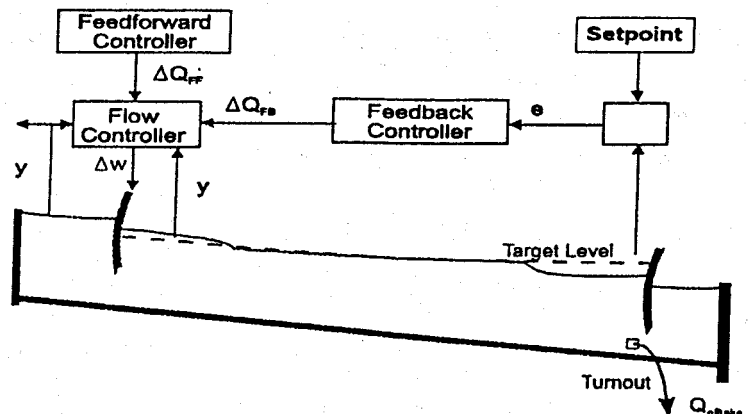


Figure 1. USWCL canal automation system components.

The routing of flow changes essentially has to be done centrally. Feedback control can be done either locally or centrally. Flow control is a local function, but it can be done either locally or centrally. In particular, flow control at in-line check structures must be turned off if the feedback controller is not functioning. Otherwise over time, the flow controller will eventually empty or overtop the canal pool immediately upstream, since inflow and outflow will never match exactly. This scheme can be used for local, centralized or cascaded (i.e., with communication between RTUs) control systems.

### *Canal Automation System Hardware*

In the past, application of canal automation has been hampered by incompatibility of system components. A significant effort is required when specifying each component in order to insure compatibility. As an example, several new irrigation systems in Arizona were designed and built to be fully automated. Remote operation required considerable hardware modification in order to function at even a rudimentary level. Details of these problems are summarized in Clemmens et al (1994). Typical hardware components for canal automation systems are shown in Table 1.

Table I. Hardware components for canal automation.

Hardware supplied by Automata	Hardware from other suppliers
Water level sensors.	Gate
Gate position sensors	Gate lifting gears
Gate motor control circuitry	Gate motor & control relays
Remote terminal unit (RTU)	Gate motor limit switches
Communications system (e.g., radio)	Central computer with peripheral devices

Compatibility is also required among the various logical components of the control system. The feedback, feed forward and flow control logic must be compatible and with appropriate transfer of information between them. For many systems, control actions should be recorded and archived, whether manual or automatic. These requirements suggest the need to embed these control functions within commercially available SCADA (Supervisory Control and Data Acquisition) packages. SCADA systems are already used by many water districts. Software components for automatic control systems are shown In Table 2. Automata plans to supply all the canal automation software shown here.

Table 2. Software components for automatic control systems

RTU logic	Communications	Central computer logic
Sensor analysis.	Type.	Closed-loop control from remote site feedback
Gate control.	Protocol.	Open-loop control for known demand changes
Closed loop control.	Baud rate.	Coordination of remote sites
	Etc.	Interface with supervisory control operators
		Interface with water ordering system
		Interface with water accounting system

*Control System Implementation*

The control industry has shifted almost entirely toward digital control systems. Thus hydraulic, mechanical and analog control systems are not considered here. With digital control systems, the selection of a control time step is an important choice. The feedback control time step is determined by canal pool response characteristics, and can be different for different canals. The flow control time step, i.e. the time when the actual control actions take place, is short relative to the feedback time step. Feedforward controls are adjusted to match the flow-control time step.

We are attempting to develop a control methodology that is as generic as possible. The separation of flow control from feedback and feedforward control makes this easier. The feed forward controller we are using is relatively straightforward, and we don't foresee the need to incorporate more complicated methods. For feedback control of water levels, the control schemes in the literature vary widely. While Ruiz, et al. (1998) attempted to put many of these schemes into a more-or-less common structure, the reality is that there are significant differences. For this implementation, we chose to use a scheme developed by Schuurmans (1995), which is less general than that suggested by Ruiz, et al. (1998). Control with this scheme can range from simple, local PI control to optimal control, with several variations in between. It can be used for downstream control, upstream control, or a combination of the two. Control parameters are globally optimized with a quadratic criteria, even if local controllers are used. The scheme also is based on flow rate differences rather than absolute flow rate to eliminate some of the errors associated with gate flow calculations and with classical control problems. More details can be found in Clemmens, et al. (1997).

As discussed above, even if the control logic for a particular gate is “local,” the control actions can still be processed centrally. Central control has advantages in that all control actions can be monitored and logged; for example, to make sure the control actions are appropriate. However, if such controls are extended to all gates in a large distribution network, the communication system may become a limitation, particularly where radio communication is used. In such cases, it makes sense to distribute the control actions and do more control locally, rather than centrally. A good application of this distributed intelligence is to perform the flow control function locally at each check structure. This would require more intelligence at the local RTU. We plan to program the flow-control function for single gates into Automata's RTUs, hopefully in a sufficiently generic form. In addition, this requires logic within the RTU to detect sensor malfunctions. Flow control for complex, multiple gate systems will initially be done centrally.

While a variety of gate position sensors are available in the marketplace, not all of them provide the degree of precision required by some of the more advanced controllers: We developed a new gate position sensor that combines two transducers; one to provide an absolute position, with a reasonable precision, and the other to provide a very precise differential reading. The two transducers are mounted on the same shaft which is rotated by a gear rack attached rigidly to the gate.

Most of the control systems discussed here require some form of communication. For many irrigation districts, radio communications is the most practical and reliable. Unfortunately there are no standard protocols for radio communications. Many SCADA and RTU vendors have their own proprietary communication protocol. While new standards are being proposed for the process control industry (e.g., FieldBus), these are not yet standardized and available for this application. ModBus is a "de facto" standard that is supported, to some degree, by many RTU manufacturers and will be used with the proposed control system.

We have chosen to use a commercial SCADA package for which we can write our own custom control routines. While many SCADA packages allow simple controllers for individual controls (e.g., a PI controller of a single gate from a single water level), very few SCADA packages are sufficiently flexible to allow the form of centralized control proposed here. We have chosen FIX by Intellution within which to embed our control routines. This SCADA package has a very flexible development environment, is widely used, and is relatively economical. In addition, it provides an interface to databases that could be tied to water ordering software.

#### *A Unique Field Test Site*

Cooperation was established with the Maricopa-Stanfield Irrigation and Drainage District to conduct research on canal automation (Clemmens, et al. 1994). This district was built with motorized gates on all check gates, even down to the smallest lateral canal. Several of these lateral canals provide a unique opportunity for canal automation research since most of the hardware was already in place. The WM-canal was chosen as a test site. It has a capacity of 2.8 m<sup>3</sup>/s. It takes water from a much larger main canal so that large flow fluctuations at the head of the WM canal can be accommodated. Several groundwater wells pump into the lateral. These can be used to simulate demand changes without having a negative impact on ongoing deliveries. Thus this allows us to test canal automation technology on a real operating system.

A number of closed loop control tests were performed on this canal during 1995. However without gate position sensors, the gate control was not reliable enough to conduct extensive tests. With the establishment of the CRADA with Automata, we installed a newer generation of RTU (purchased by USER) to test the new canal automation system and we installed the new gate position sensors developed in cooperation with Automata. Programming of these new RTUs in the FORTH computer language is ongoing. MSILD has allowed us to use their backup base station to conduct our automation research. Automata obtained a radio frequency with a four-state license for more straightforward application of their automation systems. Further testing will be - done on this canal once the automation system is programmed into the FIX SCADA system and the hardware and software components have been tested.

### *Acknowledgments*

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