

AUTOMATION OF SURFACE IRRIGATION BY CUT-OFF TIME OR CUT-OFF DISTANCE CONTROL

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ABSTRACT

An automated surface irrigation system is described that demonstrates control by either cut-off time or cut-off distance using off-the-shelf commercial products. The cut-off time control uses a standard commercial sprinkler controller to operate the gates. The cut-off distance system uses commercial radio transmitters and transceiver-relays commonly used to operate security systems or industrial processes. These systems were each installed in four irrigation basins in a 7-ha surface irrigation research facility. Over 15 irrigation events have been performed satisfactorily with minimal maintenance. While the immediate impetus for automation is likely to be the growing labor shortage, it is anticipated that water conservation benefits will be realized as well. Future research and development needs include logic control based upon variations in flow rate and soil intake rate.

INTRODUCTION

Even with rapidly increasing urbanization, agriculture is still by far the major water user in the lower Colorado River region (LCRR) accounting for 80% of the total water consumption (Arizona Department of Water Resources, 1981). Within the agricultural sector, about 95% of the area utilizes surface irrigation systems. Because of water costs, leaching requirement for salinity management, and complicated crop rotations, surface irrigation will continue to be the predominant method of irrigation in the LCRR into the foreseeable future.

Research and demonstration projects in the LCRR have shown that surface irrigation systems can be efficiently managed using volume balanced based methods for the determination of irrigation cut-off time or distance (Bali et al., 2002; Sanchez et al., 2007). Application of these methods could produce substantial water and labor savings while maintaining agricultural productivity. But adoption of these proposed efficient methods of surface irrigation management is constrained due to more intensive and skilled labor requirements and more frequent and inconvenient times at which irrigation gates must be operated. Surface irrigation is not automated like trickle and sprinkler irrigation, the presence of an irrigator is currently required, and human error and negligence are factors contributing to over irrigation.

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Considerable research on automation of surface irrigation systems has been conducted in past years. (Dedrick, 1984; Erie and Dedrick, 1978; Humpherys and Fisher, 1995). Most of this research was conducted more than fifteen years ago. Since that time, new and inexpensive products have become more widely available which can be used to automate surface irrigation systems, such as electronic timers and spread-spectrum radios. In fact, the inflation-adjusted cost of an automated system may be less (Dedrick, 1989). At the same time economic pressures have made automation more feasible, including the availability and cost of irrigation labor due to increasing economic opportunities for laborers in other sectors of the economy and more effective enforcement of immigration laws. The objective of this evaluation is to engineer and demonstrate automated systems for distance and time based cutoffs using simple off-the-shelf commercial products. Both methods have utility in the LCRR depending upon the consistency of water delivery to the farm and the soil characteristics.

MATERIALS AND METHODS

Field Description

A 7-ha of a surface irrigation system designed for previous experiments (Sanchez et al., 2007) was automated to demonstrate both distance and time based irrigation cut-off. This irrigation system uses large field turnout structures to deliver water to the borders through jack gates (gates that utilize a jack mechanism in contrast to a screw mechanism). Flow rates up to 0.6 m³/s can be delivered. The location of this demonstration project is the University of Arizona, Yuma Agricultural Center-Mesa farm (32° 36.69N 114° 37.70W). The soils are Superstition sand (sandy, mixed, hyperthermic Typic calciorthid) and the crop is mature lemons (*Citrus Limon*, Limoneira 8A Lisbon” on “Volkamariana). Four basins for each distance and time based cut-off irrigation were automated in June of 2007 and remain in use. A layout of the system is shown in Figure 1.

This field is irrigated with the downstream border (1) first and proceeding upstream in the order of the turnout number. The ditch check is operated by the sprinkler controller. After borders 1 through 4 are irrigated by cut-off time, the ditch check closes automatically and transmits a signal to turnout number 5 to open. When the water advance reaches transmitter number 5, turnout number 5 closes and turnout number 6 opens, and so on, until turnouts 5 through 8 are irrigated by cut-off distance. Turnout number 8 remains open until the operator arrives to shut off the delivery flow.

Design of the System

The system was designed to use off-the shelf commercial components and to be adaptable to any location and without a customized engineering design. For that reason, each turnout has an independent battery and solar panel. It was thought that this would be more economical since the cost of copper wire has risen sharply in recent years. It should be noted that the turnout structures are more closely spaced and the basin size is smaller than normal in the LCRR. Turnout structures are normally from 67-m to 200-m apart, and a level basin or low-gradient graded border system will normally have two turnout

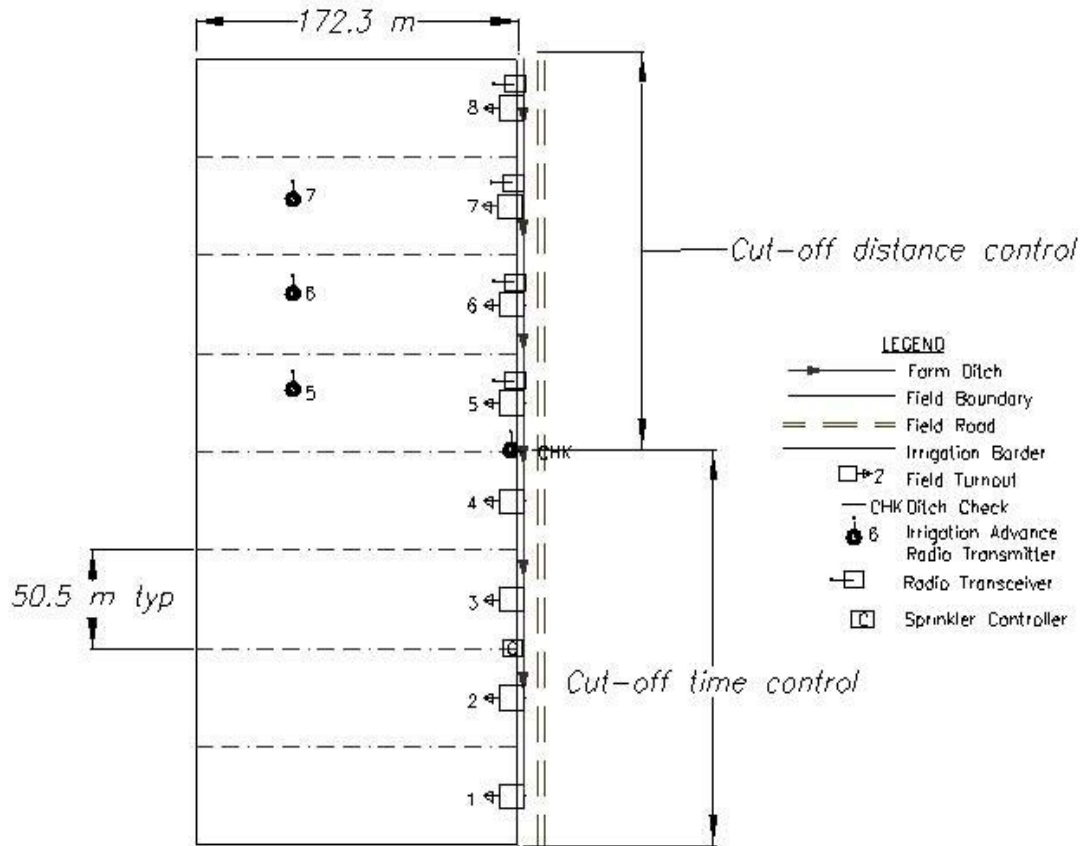


Figure 1. Layout of the system

structures opposite each other at the same location along the ditch. In practice the battery and solar panel could be used to power both turnouts, which would lower the unit cost per turnout.

The cut-off time control portion of the system uses an off-the-shelf sprinkler controller to operate the gates through standard commercial sprinkler valve control cable using 24 VAC power. The 24 VAC, normally used to operate a solenoid valve on a sprinkler system, in this case trips a relay to operate the 12 VDC actuators. A commercial-grade controller was used for this system in order to have the capability of remote, radio control in the future, but for this purpose a standard household controller would have been adequate.

The cut-off distance portion of the system uses commercial radio transmitters and transceiver-relays commonly used to operate security systems or industrial processes. For this project 2.4 GHz Spread-Spectrum radios were used due to their reliability and cost. The product that was selected was BWI Eagle model SR transmitter and transceiver. Radio transmitters were mounted on 3.2-cm diameter PVC pipe. At the base of each pipe

is a perforated section that encloses a magnetic float switch. The transmitter pole is held upright by a steel brace that can be placed by stepping on the brace with foot pressure. In this way, the transmitters can be easily moved or moved out of the way to perform tillage operations. Each transmitter is programmed with a specific frequency. There are 128 selectable digital addresses and 8 selectable frequencies with this model of radio. The range is 366 m, but the range can be doubled with some modification. When the advancing front of water reaches the float switch, the radio transmits a signal to the transceiver at the turnout gate to switch a relay and shut the gate. At the same time a signal is transmitted to the next gate in line to open.



Figure 2. Cut-off distance radio transmitter in field and transceiver at turnout

Actuators

At each jack gate, the jacking mechanism was left intact for emergency use, but disconnected by removing the bolt on the drive. The drive and the clutch were held in place with stainless steel tie wire to prevent them from catching on the jack stem during automatic operation. A 12-Volt DC actuator with a 76-cm stroke was mounted to the jack stem gate with a clamp that can be disconnected from the jack stem with a wrench during an emergency.

The jack gates are 1.16-m wide. It was determined that 113-kg force was the minimum needed for gate operation, but for safety factor a 181-kg actuator was selected. Maintenance of the gates and seals is very important in determining the amount of force that is needed. Old seals should be replaced and existing seals should be lubricated. For flow rate capacity a 0.61-m stroke would have been adequate, but a 0.76-m stroke was

selected due to the small difference in cost. These actuators operate at a speed of 1.0 cm/s at 5 amps at full load, and 1.3 cm/s at no load.



Figure 3. Actuator on Ditch Check Gate with Field Turnouts in Background

Emergency Overflow Protection

Turnout numbers 1 and 5 were wired for emergency overflow protection. A circuit similar to a tank emptying circuit was used. This is not completely secure protection against a failure of the system and consequent overflow because it depends upon a functioning power supply and actuators at turnout 1 or 5. An overflow structure in the ditch would be a preferred alternative for overflow protection. It was thought that electrical switch protection may be a second-choice alternative since it is relatively cheap and simple to adapt to an existing irrigation system. Testing showed the emergency overflow to be sufficiently reliable.

RESULTS AND DISCUSSION

During the past five months of operation, the system has performed well over 15 irrigation events with minimal maintenance. Selected cutoff times and cutoff distances were selected to optimize application efficiency based on models developed in previous research (Sanchez et al., 2007). Cut-off time control would be applicable in a situation where the grower has a dependably uniform flow rate, for example, at the upstream end of a large canal system where the canal water level is kept under close control, or a pump well for a water supply. However, cut-off time control cannot always be reliably used due to variability in flow rate that is experienced in many locations (Palmer et al., 1989).

If the flow rate of delivery could be automated to provide a uniform flow, then a cut-off time system would be more universally applicable. Cut-off distance control would likely be more reliable at the lower end of a canal delivery system or anywhere the flow rate is not dependably uniform. Both the cut off time and cut off distance systems performed adequately in our evaluations because canal delivery is relatively uniform at the location of our turnout from the main canal..

Costs of materials and labor for installation are presented (Table 1). The cut-off distance control system installation costs are about twice the cost of the cut-off time control system costs. Currently, experienced irrigators in the LCRR earn 8 to 9 dollars on hour and it takes approximately 25 to 60 minutes to irrigate a basin or border, depending on inlet flow rate, friction and bed slope, and border width and length. However, a trained irrigator could concurrently operate multiple systems in close proximity where the limitation would likely be the capacity of the district canal system in delivering water to multiple locations in close proximity. Or the irrigator could perform other farm operations concurrently with irrigation. Although these savings in labor costs would partially off-set initial capital costs, it would take more than 20 irrigations to recover the lowest installation costs presented (Table 1). Nevertheless, hiring agricultural labor is increasing difficult in LCRR, and in the short run the unavailability of labor will likely be the major impetus for such automation. The consistent application of cut off time or distance criteria will also result in water savings (Sanchez et al., 2007) but the cost of water is currently so low in irrigation districts of the LCRR (<0.4 dollars per ha/cm), these cost savings would not emerge as an important consideration in the region. However, due to a prolonged drought in the Colorado River basin, irrigation districts in the LCRR are beginning to limit total annual deliveries on an area basis and water conservation will be required to continue with the year-round cropping systems currently practiced in the region. In regions outside the LCRR, where water costs are significantly higher, reduced expenditures for water might more quickly off set the high costs of installation.

Cut-off distance control appears to be more expensive than cut-off time control and it has the additional inconvenience of having to move the transmitters whenever field machinery operations are performed. There are three ways to address or evade the additional cost and inconvenience of the cut-off distance control system: (1) Find cheaper yet robust methods of signaling the turnouts when the desired advance has been achieved; (2) Develop a system using programmable logic control that utilizes the flow rate of delivery as an input, and vary the set time to respond to variations in the flow rate; (3) Combine time control with flow rate control of the district delivery gate.

Cracking clay soils present additional needs in the development of a useable automation system. Cracking clay soils constitute a significant portion of the LCRR. A volume-balance method based on advance rate is used with these soils to determine cut-off time (Bali et al., 2001). This method requires a measurement of the advance rate on the first set that is irrigated in a soil type in order to determine the volume to apply to each set or border on the remaining borders that have the same soil type. An automation system for cracking clay soils would need one or more measurements of advance rate per irrigation

system depending on the number of soil types, and a measurement of flow rate of delivery. Other important subjects of concern in future research are cost, robustness in the elements, protection or at least discouragement against vandalism and theft, and adaptation to other types of field turnouts, in particular, pipe or “port” turnouts

Table 1. Materials and installation costs for cutoff distance and time automation.

Cost per Turnout	Cut-Off Time Control		Cut-off Distance Control:	
	One Turnout per Enclosure	Two Turnouts per Enclosure	One Turnout per Enclosure	Two Turnouts per Enclosure
Actuator	\$129	\$129	\$129	\$129
Actuator Mount	\$50	\$50	\$50	\$50
Battery	\$50	\$30	\$50	\$30
Solar Panel	\$35	\$25	\$35	\$25
Regulator	\$24	\$12	\$24	\$12
Enclosure	\$70	\$35	\$70	\$35
Radio Transceiver			\$350	\$350
Radio Transmitter			\$300	\$300
Relay	\$24	\$24		
1-mm/9wire cable (based on 120-m spacing)	\$24	\$12		
Pro-rated Trencher Rental	\$50	\$25		
Electrical Conduit and Fittings	\$20	\$20	\$40	\$40
Pro-rated Cost of Controller	\$50	\$50		
Labor for installation	\$90	\$45	\$90	\$45
Miscellaneous	\$40	\$40	\$40	\$40
Total per turnout	\$656	\$497	\$1,178	\$1,056

SUMMARY

An automated surface irrigation system was installed and operated on the University of Arizona, Yuma Agricultural Center-Mesa Farm. Automation of irrigation based on cut-off time and cut-off distance was demonstrated using off-the-shelf components. The system proved reliable over 15 irrigation events. This project should provide the basis for research into more effective and robust automation systems using programmable logic control. Automation of surface irrigation systems could provide a partial solution to growing labor shortages in the LCRR and likely result in water conservation by reducing the human error component of over-irrigation. This system could ultimately have application to surface irrigation systems across the southwestern United States.

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