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Development of a Canal Automation Model: A Laboratory Experiment

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ABSTRACT

The main objective of the project was to study and develop a canal automation model using local material and equipment. The canal automation model was developed at the Department of Irrigation Engineering, Faculty of Engineering, Kasetsart University, Kamphaengsaen campus. The model consisted of 4 gate controllers (Robogates) installed in the canal model for upstream water level control and 1 Robogate installed at the head tank to control the discharge into the canal model. Each Robogate controller is an embedded system designed to monitor the water level, gate positioning and to control the regulator. A Robogate is designed to work in 3 modes: Mode 0 (telemetering mode), Mode 1 (automatic mode) and Mode 2 (remote control). An upstream control algorithm was used for self-regulating the check gate in automatic mode. The performance of the canal automation model and the Robogates was tested in 6 runs. The farm turnout (FTO) gate was adjusted randomly to create disturbance to the flow in the canal model. The results showed that generally, the Robogate was very capable at controlling the water level in the model. The coefficient of variation of the water level upstream of the Robogate was very small, being less than 0.06 in all experiments. Two indicators˘namely the maximum control error and the unsteady period, were selected for the analysis of the performance of the canal automation model under disturbed conditions. The percent maximum error of water level from the target was smaller for the most upstream Robogate compared to the downstream Robogates. The maximum error increased from upstream to downstream. The average maximum errors were 6.6, 9.4, 20.5 and 29.2% for Robogates 1, 2, 3 and 4, respectively. Although the maximum error was rather high, particularly for the downstream Robogates, this was only for a short time during the model testing. The average percentages of maximum error in controlling the water level between the 4 Robogates were significantly ($P < 0.05$) different. This result confirmed one of the disadvantages of the upstream control algorithm. The deviation from target, either in terms of water excess or water shortage, will usually be passed to the downstream reach of the canal or any flow disturbance will be passed to the downstream canal reach. The unsteady period ranged between 2 and 8 min and was 6 min on average. The analysis of variance of the unsteady time due to the adjustment of the FTO gate showed that the average time period for each Robogate to stabilize the water level back to the target level was not significantly ($P > 0.05$) different. This laboratory experiment showed that the Robogates could remove the effect of flow disturbances within a reasonable period of 2˘8 min. This experiment helped in determining that the Robogates can be used for the effective and automatic control of the upstream water level.

Keywords: canal automation, upstream control, regulator controller, Robogate

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INTRODUCTION

The challenge for irrigation engineers is to allocate water in an equitable, efficient, reliable and timely way, while minimizing staff and operating costs (Plusquellec, 1988). One of the main factors contributing to poor performance is the lack of effective water control in irrigation canal networks. With traditional management tools, an open-channel water conveyance and delivery system is very difficult to manage in real situations, especially for a demand-oriented operation (Clemmens, 1987). The irrigation canal system in Thailand is designed for an upstream mode of operation, with the assumption of steady state flow. The water duty and command area are used to calculate the size of the canal and control structure. There is no consideration of unsteady flows that usually affect the actual canal operation and flow rate (Vudhivanich, 2008). In addition, most irrigation projects in Thailand use a gated, undershot-type, manually operated system. The advantage of this control structure is its flexibility, but it is difficult to control the flow rate in actual operation (Plusquellec *et al*., 1994) due to the high sensitivity of undershot-type gates (Renault *et al*., 2007) and the various perturbations that exist in the canal system.

The basic control concept of a canal system can be divided into 2 types: discharge or flow control; and water level control. Since the flow rate through regulators is directly related to the water level in the canal, both the water level and flow rate have to be controlled in order to deliver the desired amount of water. The general procedure for controlling the flow starts from controlling the constant water level in the main canal such that the head regulator of the secondary canal can be adjusted to control a constant desired flow rate. In a manually operated system, a large number of field operators are required to adjust the regulators continually and simultaneously; this can only be done when demand and supply do not change rapidly.

The various control methods for an irrigation canal system have been developed in order to improve the efficiency, effectiveness and flexibility of water delivery. There are 4 well-known methods of water level control˘namely upstream control, downstream control, constant volume and a variant of downstream control. These 4 control methods depend on the location of control points. If the control point is a short distance upstream of the regulator, it is called an upstream control; this is the type normally used in Thailand. If the control point is located a short distance downstream of the regulator, it is called a downstream control. This method requires that the system must be able to store the excess amount of water in the canal and so is not common practice in Thailand due to the high investment cost. For the other two methods of constant volume and the variant of downstream control, the control point is located at the mid-point and the end of the downstream reach, respectively. These 2 methods require lower investment cost compared to the downstream control. Besides the location of control, the control method can be classified according to its control pattern, which may be localized control or centralized control. For localized control, each control structure works independently according to the condition of that control structure and the system can be operated manually, remotely or automatically. For centralized control, all control structures are controlled simultaneously from the operation room and this control system usually requires a computer model and real time water measuring and control equipment. Plusquellec (2002) concluded that there was no control strategy and no equipment that was ideal for all situations found in irrigation projects. Many physical and institutional factors have to be taken into consideration by the planners and designers.

Upstream control is a common practice in Thailand, but there are some disadvantages, such as slow response and higher operational losses. For upstream control, the water delivery plan has to be established in advance. If there is an unexpected rainfall event or farmers reduce their water use, there will be an excess amount of water which is considered as a loss. Upstream control provides more advantages to the upstream users. In contrast, downstream control can respond to water demands more quickly, has lower operational losses and requires fewer field operation staff and favors the downstream users, but requires a larger canal size. A special gate (called a composite gate) was developed, so that the downstream control could be changed to upstream control when the water supply in the upstream reach was less than a specified level. Lastly, a regulating reservoir in the Doukkala and Beni-Amir irrigation projects in Morocco provides a good example of improving irrigation water delivery performance by using upstream control on the canal reaches upstream and using downstream control on the downstream reaches (Plusquellec, 1988).

At present, Thailand has 25 million rai (1 ha = 6.25 rai) of irrigated area. Most irrigation is composed of canal and farm ditch networks that use gravity to deliver and distribute water from its source to the farmland. There are discharge regulators to control the specified discharge or flow rate and water level regulators to control the water level in the canal at full supply level (FSL). According to the upstream control principles, the field operators have to adjust both the discharge and water level regulators to control the target flow in the canal system. The key factors of success are planning, controlling and monitoring the water delivery. A software program, water allocation scheduling and monitoring (WASAM), was developed to assist irrigation projects in planning and monitoring water delivery by computer. WASAM has been modified from time to time and tested in many irrigation projects (Vudhivanich *et al*., 2000). This process is still not widely accepted in actual operational practice, due to the requirement for a large amount of weekly input data for WASAM and the difficulty of manual gate operation. There has been very little development in the field of flow control in Thailand. Most canal systems are operated manually and require a high number of field operators who are lacking in most projects. Hydraulic type automatic gates, such as a commercial Neyrtec AMIL gate, have been employed in the Klong Tron and Song Phi Nong irrigation projects, but they have not been applied in other irrigation projects due to the high investment cost and patent problems.

Nowadays, computer and information technology plays an important role in remote monitoring and control, which can be useful in water management. An automatic canal control system in connection with SCADA (supervisory control and data acquisition) systems can improve irrigation canal management, substantially increase water use efficiency and the quality of the deliveries and, at the same time, save on labor and reduce construction costs (Rijo, 1999). Canal automation was tested and implemented in the Salt River Project (SRP) and the Maricopa Stanfield Irrigation and Drainage District, Central Arizona, to improve the water delivery service to farmers, reduce operating costs and improve distribution efficiency (that is reduce unaccounted losses). The implementation of canal automation through these two projects demonstrated the capabilities and limitations of this technology (Clemmens *et al.*, 1997). SCADA and telemetering systems have been employed in some water projects in Thailand, including irrigation projects, with most using imported equipment and technology requiring high investment and operation costs. For example, SIC (simulation of irrigation canal) software developed by Cemagref, France, costs USD 16,000 for the professional version (Malaterre and Baume (undated)). Vudhivanich and Sriwongsa (2004) developed a low cost micro-controller and sensors for remote monitoring and control of the regulator. A test with 3 regulators during August to December 2003 at the Bang Lane irrigation project, Nakhon Pathom province produced a satisfactorily result, with an average error of 2.3%. The Bang Lane micro-controller and sensors needed further development in order to increase the capability for remote monitoring and control of regulators in an irrigation canal system. Burt and Piao (2002) stated that some key ingredients for any acceptable canal automation model include the hydraulic correctness of steady and unsteady flow conditions, short simulation time steps (1 sec), capability to automatically solve for initial steady state conditions, including all water surfaces, flow rates and gate positions, and quick computational speed. The objectives of the present research were to develop a physical canal automation model which could be used to control a series of regulators in an irrigation canal and to test its performance at the laboratory scale.

MATERIALS AND METHODS

The steps used in the methodology for this research were to:

1) Develop a canal automation model at the laboratory scale that could represent general irrigation water delivery using micro-controller technology. The canal automation model, 4 m wide and 8 m long, consisted of one water supply tank and 5 regulators. The water level sensors, gate positioning sensors, gate controllers (known as Robogates in the present study), computer interface via VHF radio for remote communication and canal water control software used in the canal automation model were developed using locally available material and technology.

2) Develop the algorithm for upstream water level control in the irrigation canal.

3) Test the performance of the canal automation model on upstream water level control under disturbed conditions and analyze the water level control performance of the Robogates and the canal automation model.

RESULTS AND DISCUSSION

Development of canal automation model

The canal automation model was developed at the Department of Irrigation Engineering, Kasetsart University, Kamphaengsaen, Nakhon Pathom province in order to test the performance the Robogates, the water level and gate positioning sensors and the canal operation software under laboratory conditions. The canal automation model (Figure 1) had the components described below;

1) 0.5 m^3 head tank with siphon spillways

2) Fiberglass canal with trapezoidal cross section, 20 cm bed width, 35 cm height, 1:0.6 side slope, 1:2,000 longitudinal slope and 14 m length

3) 10 cm-3 hp centrifugal pump with a maximum pumping capacity of 15 L/sec.

4) 5 Robogates, the first Robogate was used to monitor and control the discharge from the head tank to the canal model, Robogates 2-5 were used to monitor and control the water level upstream of the 4 cross regulators (15 cm wide and installed 3˘4 m apart) in the canal model. The Robogate is an embedded system with 5 analog-to-digital convertor (ADC) ports, 2 motor control circuit (MCC) ports , a pressure transducer and 1 Citizen Band (CB) communication radio. The functions of each Robogate were to monitor the water levels and gate positions of the cross regulator and to control the gate adjustment.

5) Telemetering units were used to monitor the water level by floating type-5 Ω potentiometer water level sensors installed in each canal section upstream of each Robogate.

6) 4 manually operated offtakes, with each offtake installed just upstream of a Robogate.

7) A master station to communicate with the 5 Robogates and the 2 telemetering units via 0.5 W CB-communication radio in order to monitor the water level and gate positioning or to

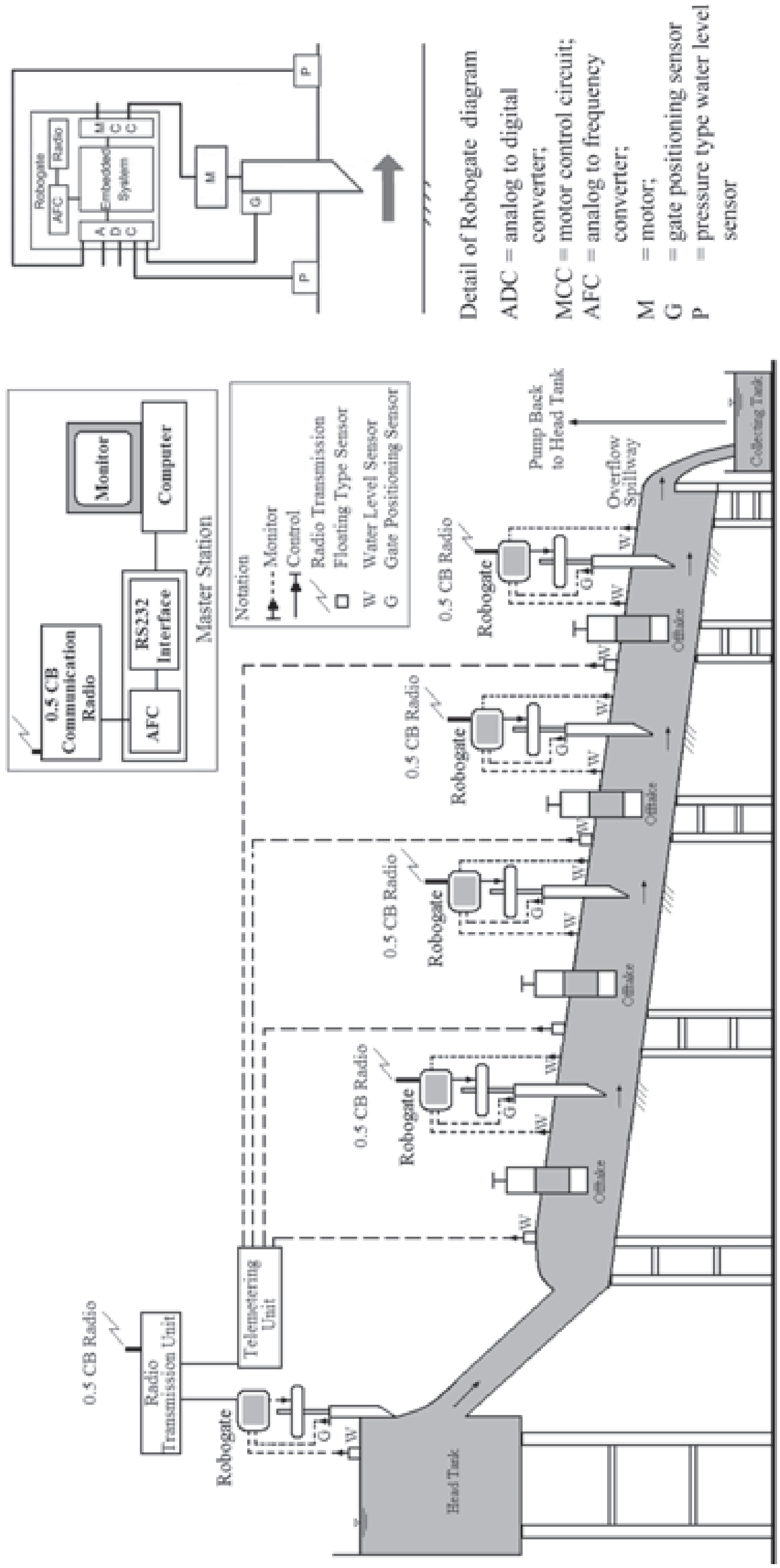


Figure 1 Diagram of canal automation model.

control the 5 regulators. The master station consisted of 1 desktop computer and the canal automation interface for communication with the Robogates and the telemetering units via 0.5 W CB communication radio.

The canal automation model is shown with Robogates, farm turnout (FTO) and master station in Figure 2.

The canal automation model was designed to operate in 3 modes. Mode 0 or the telemetering mode allows the computer at the master station to retrieve the water level and gate positioning data from the Robogate and FTO. Mode 1 or the automatic mode allows each Robogate to monitor the water level every 30 sec and self-adjust the gate in order to control the water level upstream of the regulator to the target level. The control algorithm of this mode of operation is explained in the next paragraph. Mode 2 or the remote control mode allows operators to control the gates of the regulators and FTOs from the master station to a pre-specified discharge. In the present experiment, the automatic mode (Mode 1) of the canal automation model was tested.

Upstream control algorithm for automatic mode

A Robogate is designed to perform automatic upstream water control for Mode 1 operation using the upstream control algorithm. Using this algorithm, Robogate will read the upstream water level (y) 5 sec after gate adjustment. The water level y will then be converted to the volume of water (V) in the upstream reach. The functional relationship between V and y depends on the configuration on the canal reach, the trapezoidal cross section and the reach length. The actual volume of water in the upstream reach (V) is compared to the target control volume (V_{target}). If the actual volume is greater or less than the target control volume, the deviated volume is calculated by Equation 1:

$$\Delta V = V - V_{target} \quad (1)$$

where:

ΔV = the deviated volume of water in the control reach from the target (m^3)

V = the actual volume of water in the control reach (m^3)

V_{target} = the target volume of water in the control reach (m^3)

A positive value of ΔV means there is some excess water in the upstream reach and the gate will have to be adjusted (opened wider) to increase the discharge in order to maintain the constant volume in the upstream reach. A negative value of ΔV means the opposite and the gate opening has to be adjusted to reduce the discharge. The release interval (Δt) is selected, (5 sec), in order to determine the new discharge (Q_t) by Equation 2:

$$Q_t = Q_{t-1} + \frac{\Delta V}{\Delta t} \quad (2)$$

where:

Q_{t-1} = the present discharge (m^3/sec)

Q_t = the new discharge (m^3/sec)

The new gate opening (Go) can be calculated once the new discharge (Q_t) is known using the gate flow formula. In this canal automation model (CAM), the submerged orifice formula was used (Equation 3):

$$Q = CBG_o\sqrt{2g\Delta h} \quad (3)$$

where:

Q = discharge (m^3/sec)

C = discharge coefficient depending on the gate characteristics

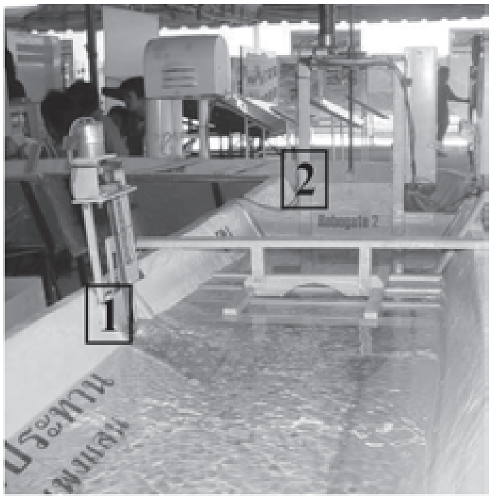
B = gate width (m)

Go = gate opening (m)

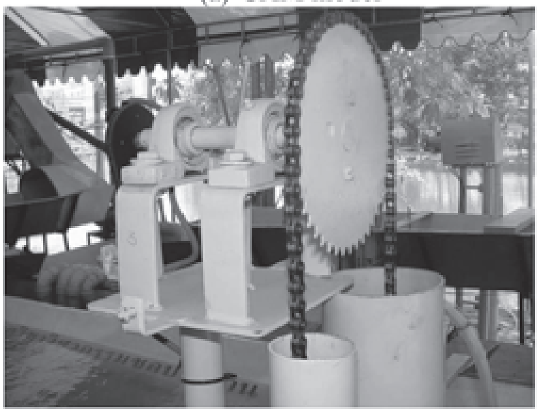
g = 9.81 m/s^2

Δh = head difference (m) = upstream water level - downstream water level

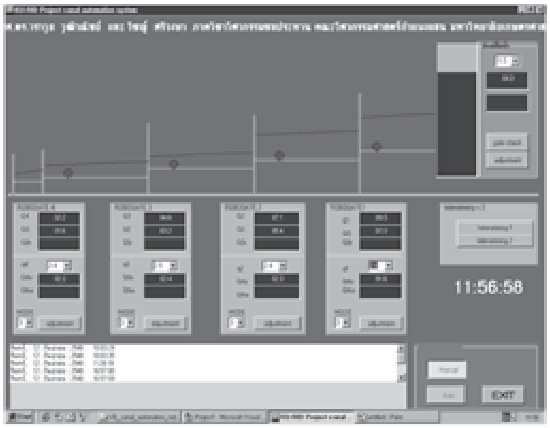
(a) CAM model



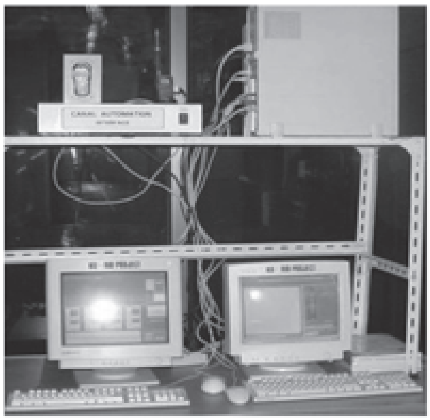
(b) FTO (1) and Robogate (2)



(c) Floating type water level connected to potentiometer



(d) Monitoring of water level and gate positioning in real-time operation at master station



(e) Canal automation interface transferring the water level and gate position data between computer at master station and each Robogate via CB communication radio

Figure 2 Canal automation model (CAM) and its main components.

After the gate has been adjusted, the process is repeated. Each Robogate works independently to control the upstream water level. This algorithm is called local control.

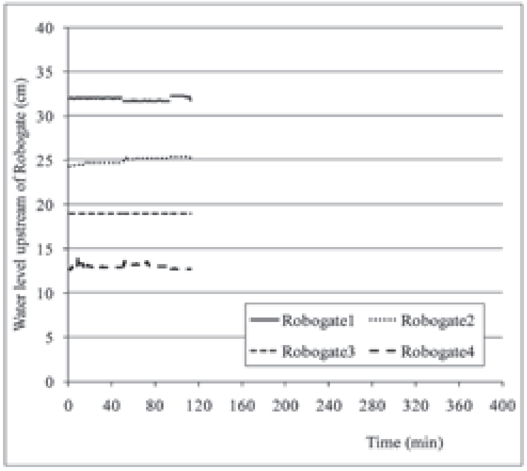
Performance for upstream water level control

The canal automation model was tested in the laboratory of the Department of Irrigation Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University to check the performance of the Robogates on the upstream water level control. Six test runs were performed with 0˘5 FT O gate adjustments randomly in order to observe how much the FTO gate adjustment could disturb the flow in the canal and how effective the Robogates were at stabilizing the water level in the canal automation model. The water levels upstream of the 4 Robogates were recorded and are plotted in Figure 3. The statistical properties of the recorded water level upstream of the Robogates are given in Table 1. Without any FTO gate adjustment, the water level upstream of the 4 Robogates showed very little variation, the values of the coefficient of variation (CV) were less than 0.018. It can be seen that the FTO gate adjustment disturbed the flow and temporarily caused a substantial increase in the water level variation (Figures 3b-3e) compared to the case

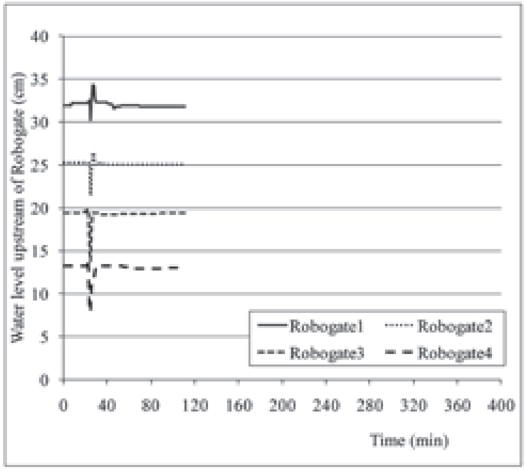
Table 1 Statistical properties of recorded water level upstream of Robogates.

Case	Statistic	Robogate1	Robogate2	Robogate3	Robogate4
No FTO gate adjustment	n	111	111	111	111
	$\bar{x}$ (cm)	32.0	25.0	19.0	13.0
	SD (cm)	0.2	0.3	0.0	0.2
	CV	0.007	0.013	0.000	0.018
1 FTO gate adjustment	n	111	111	111	111
	$\bar{x}$ (cm)	32.0	25.0	19.2	12.9
	SD (cm)	0.4	0.4	0.7	0.8
	CV	0.013	0.016	0.035	0.059
2 FTO gate adjustments	N	224	224	224	224
	$\bar{x}$ (cm)	33.1	24.2	19.6	13.5
	SD (cm)	0.4	0.3	0.5	0.5
	CV	0.012	0.012	0.027	0.038
3 FTO gate adjustments	N	206	206	206	206
	$\bar{x}$ (cm)	32.4	24.9	19.3	13.1
	SD (cm)	0.5	0.6	0.7	0.6
	CV	0.017	0.024	0.038	0.042
4 FTO gate adjustments	N	275	275	275	275
	$\bar{x}$ (cm)	32.2	25.0	18.8	13.0
	SD (cm)	0.5	0.4	0.6	0.7
	CV	0.015	0.018	0.034	0.054
5 FTO gate adjustments	n	372	372	372	372
	$\bar{x}$ (cm)	32.1	24.9	18.7	13.0
	SD (cm)	0.3	0.5	0.7	0.6
	CV	0.009	0.019	0.037	0.047

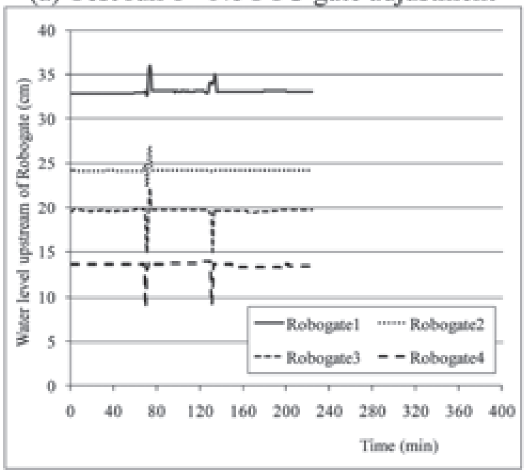
n = number of observations; $\bar{x}$ and SD are mean and standard deviation of the upstream water level, respectively; CV = coefficient of variation = SD / $\bar{x}$.



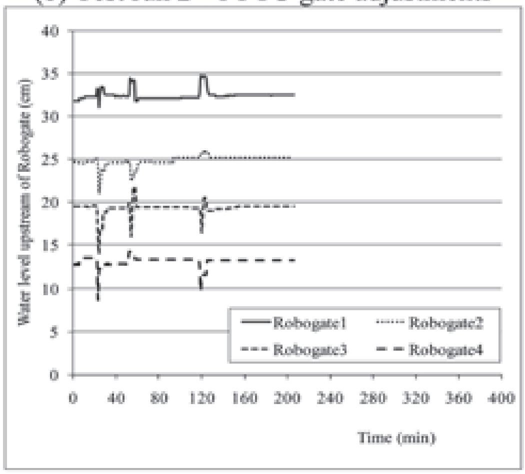
(a) Test run 1 – No FTO gate adjustment



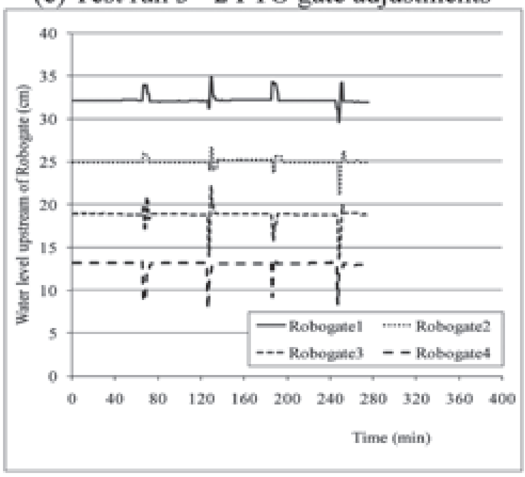
(b) Test run 2 – 1 FTO gate adjustments



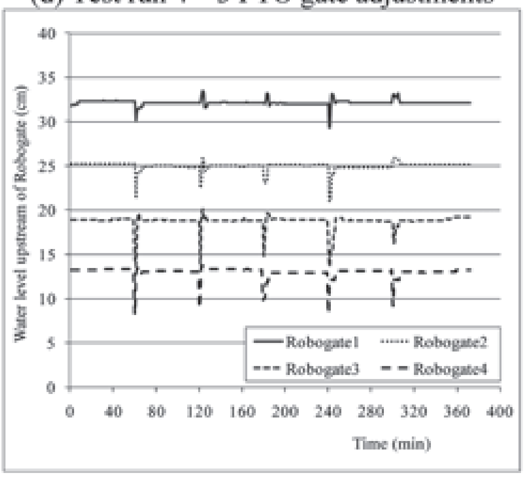
(c) Test run 3 – 2 FTO gate adjustments



(d) Test run 4 – 3 FTO gate adjustments



(e) Test run 5 – 4 FTO gate adjustments



(f) Test run 6 – 5 FTO gate adjustments

Figure 3 Water level upstream of the 4 Robogates during test runs 1 ˘ 6.

with no FTO gate adjustment (Figure 3a). The CV for the cases with FTO gate adjustment increased substantially, particularly at Robogate 4, the most downstream Robogate, where the CV increased 2 to 3 times. However in all cases, the CV values were very small (less than 0.06) indicating the capability of the 4 Robogates to control the water level in the canal automation model.

The target water control levels upstream of the Robogates in all test runs are given in Table 2. When the FTO gate was adjusted, the state of flow in the canal was disturbed. The water level upstream of the Robogates changed from the control level. Each Robogate adjusted the check gate automatically and independently according to the water control algorithm (detailed in the previous section) in order to maintain the water level at its target level. The parameters of flow disturbance due to the FTO gate adjustment were measured including the magnitude and duration of water level variation from the target. The maximum error measured as a percentage (100 x maximum water level deviation from target / target water control level) was used as the magnitude of flow disturbance, while the unsteady period measured in minutes was used as the duration of flow disturbance. The parameters of flow disturbance for the cases of 1 to 5 FTO gate adjustments are shown in Table 3.

As shown in Table 3, the percent maximum error of water level from the target was smallest for the Robogate that was furthest upstream. The percent maximum error in water level control increased from upstream to downstream. The average maximum errors were 6.6, 9.4, 20.5 and 29.2% for Robogates 1, 2, 3 and 4, respectively. Although the maximum errors were rather high, particularly for the downstream Robogates, this only lasted for a short time in the model test. The analysis of variance in Table 4 shows that the *P*-value approached zero. This analysis confirmed that the average percentages of maximum error in controlling the water level of the 4 Robogates were significantly ($P < 0.05$) different. This conclusion confirmed one of the disadvantages of the upstream control algorithm; the deviation from the target either in terms of water excess or water shortage will usually be passed to the downstream reach of the canal, or any flow disturbance will be passed to the downstream canal reach.

From Table 3, the unsteady period ranged between 2 and 8 min, with an average of 6 min. The analysis of variance of the unsteady time due to the adjustment of the FTO gate showed that the average time period for each Robogate to stabilize the water level back to the target level was not significantly different ($P > 0.05$) as shown in Table 5. This indicated that each Robogate could remove the effect of flow disturbances within a reasonable period (2˘8 min). This experimental result was close to the physical canal model study of Rijo (2003) using a proportional-integral (PI) controller, where it was reported that the PI controller was able to bring the water depth back to the setpoint (700 mm) within 5 min. Therefore, the present experiment helped confirm that Robogates had the potential for effective automatic control of the upstream water level and that a field test was worth further investigation.

Table 2 Target water control level upstream of Robogates in the canal automation model.

Robogate	Target water control level upstream of Robogate (cm)
1	32
2	25
3	19
4	13

Table 3 Flow disturbance parameters due to FTO gate adjustments.

Case	FTO gate adjustment	Disturbance parameter	Robogate1	Robogate2	Robogate3	Robogate4
1 FTO gate adjustment	1	Max. error (%)	7.2	14.4	27.4	39.2
		Unsteady period (min)	5	5	4	7
2 FTO gate adjustment	1	Max. error (%)	2.8	3.6	3.7	4.6
		Unsteady period (min)	5	5	4	7
	2	Max. error (%)	12.5	10.4	21.6	32.3
		Unsteady period (min)	4	6	6	2
3 FTO gate adjustment	1	Max. error (%)	4.4	15.6	26.3	33.1
		Unsteady period (min)	8	8	6	2
	2	Max. error (%)	7.5	10.0	15.8	9.2
		Unsteady period (min)	6	7	7	8
	3	Max. error (%)	8.4	4.0	13.2	25.4
		Unsteady period (min)	7	3	7	7
4 FTO gate adjustment	1	Max. error (%)	5.9	4.0	10.5	32.3
		Unsteady period (min)	7	7	6	7
	2	Max. error (%)	9.1	6.8	26.3	39.2
		Unsteady period (min)	5	5	6	5
	3	Max. error (%)	7.2	5.2	16.8	29.2
		Unsteady period (min)	7	4	6	2
	4	Max. error (%)	7.5	15.6	28.4	35.4
		Unsteady period (min)	5	7	5	2
5 FTO gate adjustment	1	Max. error (%)	5.6	14.8	27.9	36.9
		Unsteady period (min)	6	6	6	5
	2	Max. error (%)	4.7	10.0	26.3	30.8
		Unsteady period (min)	4	5	4	3
	3	Max. error (%)	3.8	8.0	21.6	24.6
		Unsteady period (min)	4	5	7	7
	4	Max. error (%)	8.4	16.0	27.9	36.2
		Unsteady period (min)	6	6	8	8
	5	Max. error (%)	3.8	3.2	14.2	29.2
		Unsteady period (min)	7	7	6	8

Table 4 ANOVA of maximum error (%) showing a significant ($P < 0.05$) difference between Robogates.

Source of variation	SS	df	MS	F	*P*-value
Treatment (Robogate)	4877.2	3	1625.731	33.96	0.0000
Error	2681	56	47.874		
Total	7558.2	59			

Table 5 ANOVA of unsteady period (min) showing no significant difference ($P > 0.05$) between Robogates.

Source of variation	SS	df	MS	F	*P*-value
Treatment (Robogate)	2.4	3	0.800	0.29	0.8303
Error	152.9	56	2.731		
Total	155.3	59			

CONCLUSION

A canal automation model was developed at the Department of Irrigation Engineering, Faculty of Engineering, Kasetsart University, Kamphaengsaen campus. The model consisted of 4 Robogate controllers installed 3-4 m apart in a canal for upstream water level control and 1 Robogate was installed at the head tank for controlling the discharge into the canal model. Each Robogate controller is an embedded system designed to monitor the water level, adjust gate positioning and self-regulate the cross regulator. Each Robogate used the upstream control algorithm for self-regulating the check gate in automatic mode. The performance of the canal automation model and the Robogates was tested with 6 experimental runs. The FTO gate was adjusted randomly to create disturbance to the flow in the canal model. The results showed that the Robogates were very capable at controlling the water level in the model. The values of the coefficient of variation of the water level upstream of the Robogates were very small in all experiments (less than 0.06). The Robogates were able to remove the disturbance due to the FTO gate adjustment within a reasonable time of between 2 and 8 min. The experiment showed the potential of the Robogates and the canal automation system to be used for actual flow control in an irrigation canal.

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