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Field Performance of Kamphaengsaen Canal Automation System

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ABSTRACT

The Kamphaengsaen canal automation system (KPS CAS) was developed for real time monitoring and regulation of the flow in the canal irrigation system of Kasetsart University, Kamphaengsaen campus, Nakhon Pathom province. KPS CAS consists of five remote terminal units (RTUs) and a master station. Robogate, a low cost micro-controller embedded system was used to function as RTUs for flow monitoring and control in the irrigation canals of Kamphaengsaen campus. Two types of Robogate were used—namely, a water level control Robogate installed at a cross regulator and a discharge control Robogate installed at a head regulator. Upstream water level control and constant volume control were algorithms of KPS CAS that were used for the water level and discharge control, respectively. The master station installed at the Department of Irrigation Engineering located more than 1 km from the Kamphaengsaen canal irrigation system was designed to poll the data from the RTUs every half an hour via citizen band 245 MHz radio. The KPS CAS was tested for 600 d during the period from 10 October 2006 to 1 June 2008. The various field performances of the canal automation system were studied including the accuracy of the floating-type water level and gate positioning sensors, performance characteristics of the upstream water level control algorithm, reliability of data measurement and the overall control performance of the KPS CAS. The results showed that both sensors had a very small error of measurement. The characteristics of water level and gate adjustment of Robogate 9021 were observed at 5 sec intervals, producing more than 20,200 data records, in order to check the effectiveness of the upstream control algorithm. When the upstream water level deviated from the target water level, the gate was adjusted 4–12 times automatically, within a duration of 310–780 sec, until the upstream water level was maintained at the target level. During the test period of 600 d, 17.3% of data were missing due to unexpected disturbances and failures. The automatic mode operation was compared to the manual operation. The root mean square error of the target water level control in the automatic mode (0.009–0.013 m), was considerably smaller than that of the manual mode (0.118–0.178 m). With smaller water level fluctuations at the cross regulators, the head regulator could produce a more uniform discharge into the canal. Therefore it could be concluded that the KPS CAS is useful for flow control.

Keywords: canal automation, canal control, irrigation, Robogate, Kamphaengsaen

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INTRODUCTION

Water allocation and delivery in an equitable, efficient, reliable and timely way, while minimizing staff and operating costs, is a challenge for irrigation engineers (Plusquellec, 1988). The main factor contributing to poor water delivery 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 control principle, without consideration of unsteady flows that usually affect the actual canal operation and flow rate (Sriwongsa and 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 various control methods for an irrigation canal system have been developed in order to improve the efficiency, effectiveness and flexibility of water delivery. Those methods are upstream control, downstream control, constant volume and a variant of downstream control. Upstream control is a common practice in Thailand, but there are some disadvantages. 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.

Nowadays, computers and information technology play an important role in remote monitoring and control, which can be useful in water management. An automatic canal control system in connection with supervisory control and data acquisition (SCADA) systems can improve irrigation canal management. It can 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 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 to 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. They mostly rely on imported equipment and technology which leads to high investment and operating costs. In 2003, Vudhivanich and Sriwongsa (2004) developed a low cost micro-controller and sensors for remote monitoring and control of the regulator. A test with three regulators during the period from August to December 2003 at the Bang Lane irrigation project, Nakhon Pathom province produced a satisfactorily result, with an average error of 2.3%.

In order to study flow control more comprehensively, a canal automation model, 4 m wide and 8 m long, consisting of one water supply tank and five regulators was developed in the laboratory of the Department of Irrigation Engineering, Faculty of Engineering, Kasetsart University, Kamphaengsaen campus (Vudhivanich and Sriwongsa, 2011). A micro-controller embedded system called Robogate was developed to monitor the water level and gate positioning and to control the regulator for the model. Four

Robogate controllers were installed 3–4 m apart in a model canal for upstream water level control and one Robogate was installed at the head tank for controlling the discharge into the canal model. A Robogate is designed to work in three modes: Mode 0 (telemetering mode), Mode 1 (automatic mode) and Mode 2 (remote control). An upstream control algorithm was used to self-regulate the check gate in automatic mode. The performance of the canal automation model and the Robogate was tested in six runs. The results showed that generally, the Robogate was very capable in 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 (which was defined as the period of water level variation beyond the control tolerance)—were selected for the analysis of the performance of the canal automation model under disturbed conditions. 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 in the model. However, field experiment was needed to confirm the accuracy and effectiveness of the canal automation system, Robogate and the sensors. In 2006, the canal automation system was developed for the monitoring and control of flow parameters in the irrigation system of Kasetsart University, Kamphaengsaen campus. This system is called the Kamphaengsaen canal automation system or KPS CAS (Sriwongsa and Vudhivanich, 2008). The objective of the present research was to assess the performance of the Kamphaengsaen canal automation system under field conditions.

MATERIALS AND METHODS

Kamphaengsaen irrigation canal system

The irrigation system of Kasetsart University, Kamphaengsaen campus consists of the main storage reservoir (Reservoir 1), the main canal (MC) and one lateral canal (1L-MC) which can supply irrigation water to 720 ha of cultivated crop area on the Kamphaengsaen campus. Reservoir 1 has a storage capacity of 0.9 million m^3. It was designed to re-regulate irrigation water that was supplied from 1L-6R-2L of the Phanomtuan O&M project of the Greater Mae Klong Irrigation System to the campus irrigation system. The main canal (MC) has a delivering capacity of 1 $m^3.sec^{-1}$ with the total main canal length being 3.6 km. The lateral canal, 1L-MC, has a total length of 3.25 km. The main crops are sugarcane, paddy, pasture, vegetables, upland crops and fish farms. A map of the Kamphaengsaen canal irrigation system is shown in Figure 1(a). The detailed characteristics of the canals are shown in Table 1.

Table 1 Characteristics of irrigation canals on Kamphaengsaen campus.

Canals	Length (km)	Canal specifications				
		B (m)	D (m)	SS	Longitudinal slope	Irrigation area (ha)
MC	0+000-0+725	0.80	0.65	1:1.5	1:5,000	96
	0+725-2+175	0.60	0.45	1:1.5	1:6,000	400
1L-MC	0+000-1+200	0.90	0.50	1:1.5	1:5,000	104
	1+200-2+500	1.10	0.50	1:1.5	1:7,000	120
					Total	720

Length=length of canal section between two Robogates; B = bed width; D = water depth; SS = side slope

Kamphaengsaen canal automation system

The Kamphaengsaen canal automation system (KPS CAS) was developed by the authors for the automatic control of irrigation water delivery in the canal system of Kasetsart University, Kamphaengsaen campus (Sriwongsa and Vudhivanich, 2008). The design of the canal automation system was based on experience gained from several laboratory experiments on the canal automation model conducted by Vudhivanich and Sriwongsa (2011) at the Department of Irrigation Engineering, Kasetsart

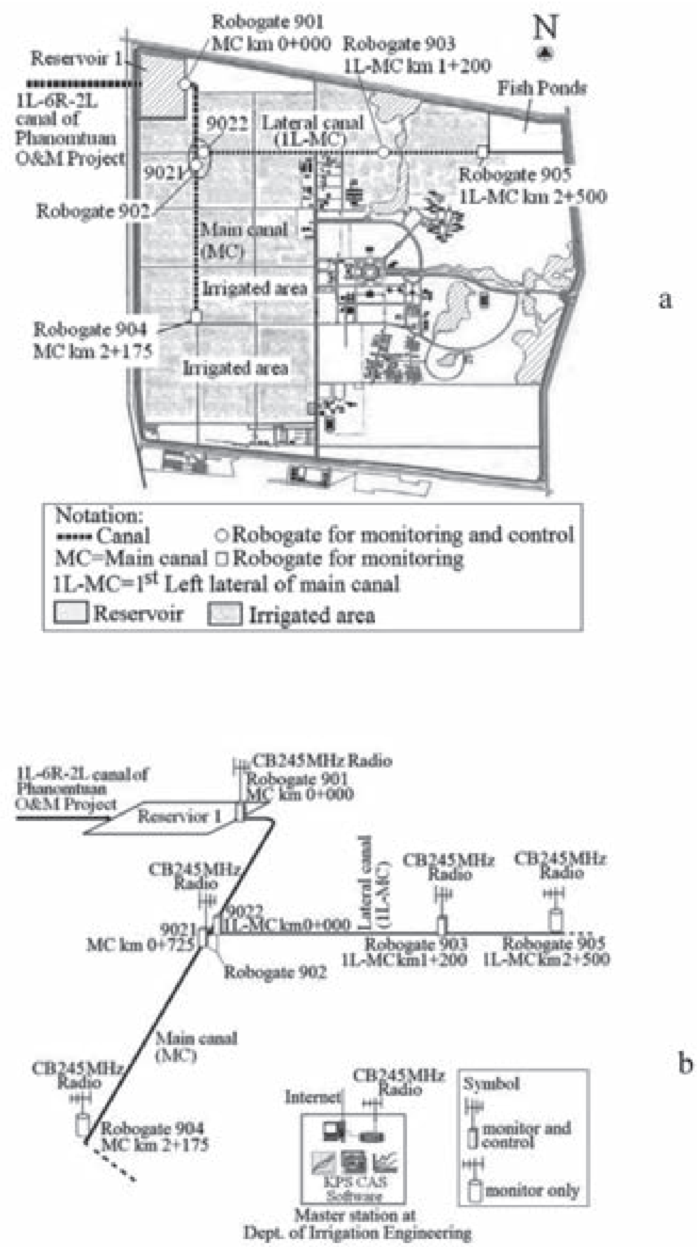

Figure 1 Kamphaengsaen canal automation system (KPS CAS) showing: (a) Kamphaengsaen irrigation system; and (b) Layout of KPS CAS.

University during 2005–2006. The system consisted of five remote terminal units (RTUs) installed in the canal system and a master station installed at the Department of Irrigation Engineering. Robogate, an embedded system with five analog-to-digital convertor ports and 1 citizen band (CB) communication radio and an optional motor control circuit, were used as RTUs. Each Robogate was designed to undertake a different function. Robogate 901 was installed at the head regulator to monitor and control discharge from Reservoir 1 into the main canal. Robogate 902 installed at the junction of 1L-MC was more complicated than the others and consisted of two micro-controller embedded systems called 9021 and 9022. The embedded micro-controller 9021 was designed to monitor and control the water level upstream of the cross regulator at MC km 0+725. The embedded micro-controller 9022 of Robogate 902 was designed to monitor and control the discharge at the head regulator of 1L-MC. Robogate 903 was installed at the 1L-MC km 1+200 cross regulator for water level control. Robogates 904 and 905 were installed at the tail ends of the main canal and the 1L-MC lateral canal, respectively, to monitor the tail water level. The volume control algorithm was used for discharge control of the head regulator, and the upstream water level control algorithm was used for the water level control of the cross regulator. The layout of the KPS CAS is shown in Figure 1(b). The components and functions of the KPS CAS are described in Table 2. Photographs of the Robogates and master station are shown in Figure 2.

Control algorithm of KPS CAS

The KPS CAS was designed to monitor and control the flow parameters including the water level and regulator gate opening. The Robogate installed at the cross regulator automatically controls water level upstream of the cross regulators to the pre-specified target water level using the upstream control algorithm as shown in Figure 3. Every 30 min, the computer at the master station monitors the flow conditions (water levels, gate openings and gate discharges) via radio transmission from the Robogates. The data are recorded in the database. The discharge requirements of the head regulators are analyzed using the constant volume control algorithm shown in Equations 1–3. The new gate settings of the head regulators are determined by the submerged flow formula in Equation 4. Finally, the master station commands the Robogate at the head regulator to adjust the gate according to the new discharge requirements.

$$\Delta V = \Delta WL \times L \qquad (1)$$

$$\Delta Q = \frac{\Delta V}{\Delta t} \qquad (2)$$

$$Q_t = Q_{t-1} \pm \Delta Q \qquad (3)$$

$$Q_t = C_s L h_s \sqrt{2g\Delta h} \qquad (4)$$

$$C_s = C_1 \left(\frac{h_s}{G_o} \right)^{c_2} \qquad (5)$$

where, ΔWL = cross sectional area of the canal flow deviated from the target area (m^2); ΔV = deviation of the volume of water in the downstream reach from the target volume (m^3); L = length of downstream canal reach (m); Δt = time interval for discharge adjustment to maintain constant volume; ΔQ = additional discharge to maintain the constant volume in downstream reach ($m^3.s^{-1}$); Q_t = required discharge of the head regulator for the next 30 min ($m^3.s^{-1}$); Q_{t-1} = present discharge ($m^3.s^{-1}$); C_s = submerged flow discharge coefficients**;** L = gate width (m); h_s = downstream water elevation (m) – gate threshold elevation (m); G_o = gate opening (m); g = gravity acceleration ($m.s^{-2}$); Δh = upstream water surface elevation (m) – downstream water surface elevation (m); C_1, C_2 = calibrated discharge coefficients of Equation 5 as shown in Table 3.

The field experiments were conducted to test the various aspects of performance of the canal automation system—namely, 1) the accuracy of

Table 2 Details of KPS CAS.

Component	Details	Location	Function
Robogate 901	Embedded micro-controller 2 floating type water level sensors 1gate positioning sensor 12V-DC gear motor	MC head regulator at km 0+00	Monitor and control discharge through MC head regulator
Robogate 902	2 sets of embedded micro-controller; 9021 and 9022 3 floating type water level sensors 2 gate positioning sensors 2 DC gear motors (12V)	1L-MC junction	Monitor and control water level upstream of MC cross regulator at km 0+725 Monitor and control discharge through 1L-MC head regulator
Robogate 903	Embedded micro-controller 2 floating type water level sensors 1gate positioning sensor 1 DC gear motor(12V)	1L-MC cross regulator at km 1+200	Monitor and control water level upstream of 1L-MC cross regulator at km 1+200
Robogate 904	Embedded micro-controller; 1 floating type water level sensor	Tail end of MC, km 2+175	Monitor water level at the tail end of MC km 2+175
Robogate 905	Embedded micro-controller; 1 floating type water level sensor	Tail end of 1L-MC, km 2+500	Monitor water level at the tail end of 1L-MC km 2+500
Master station	Computer canal automation interface CB transmission radio canal automation software	Department of Irrigation Engineering, Kamphaengsaen campus	Retrieve water level, gate opening and flow data from Robogates and record on datalogger Calculate discharge requirements and new gate settings for head regulators at MC km 0+000 and 1L-MC km 0+000 Feedback the new gate settings to Robogates

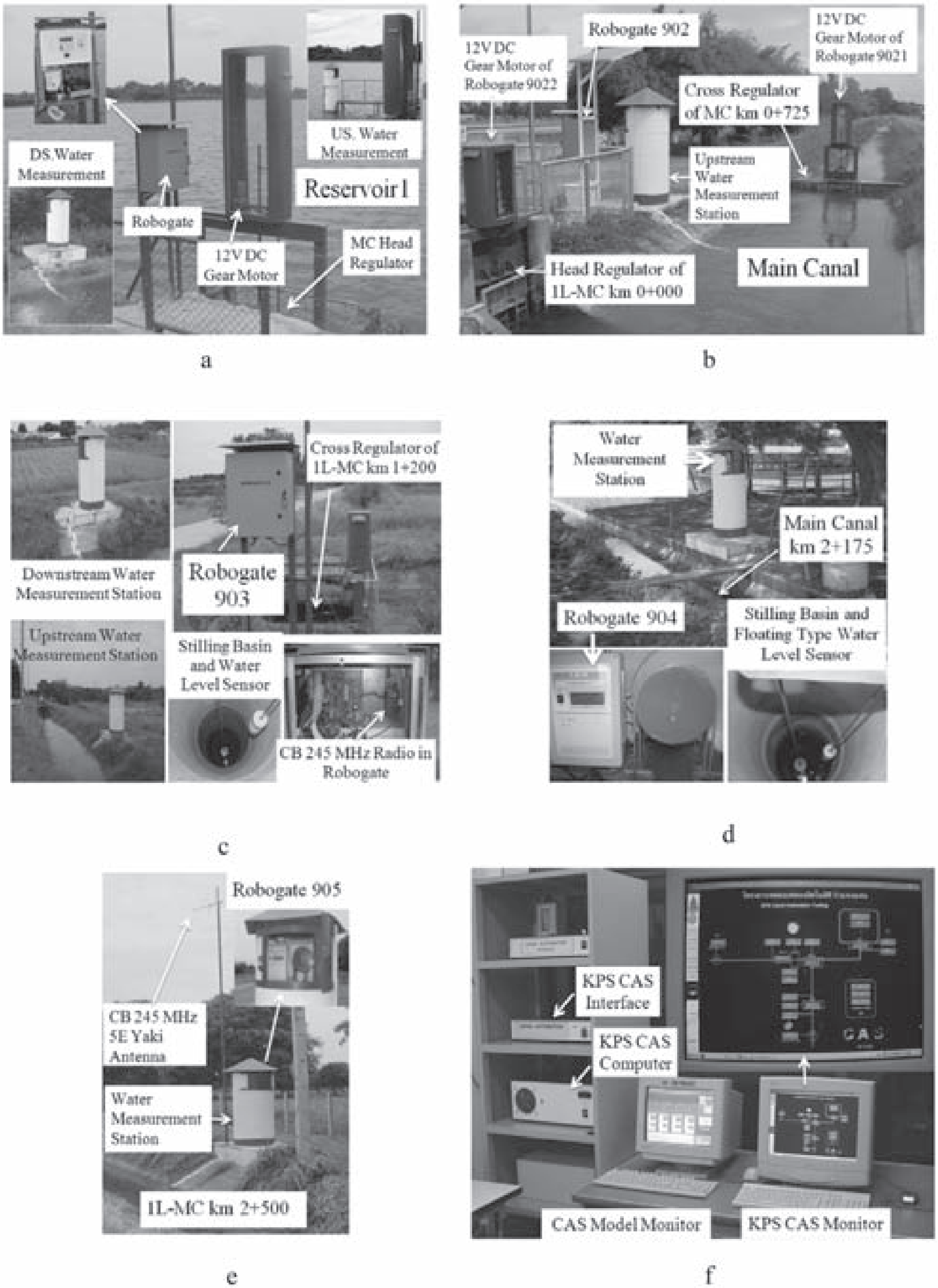

Figure 2 Robogates and master station of Kamphaengsaen canal automation system (KPS CAS): (a) Robogate 901 at head regulator of MC km 0+000; (b) Robogate 902 at junction of 1L-MC; (c) Robogate 903 at cross regulator of 1L-MC km 1+200; (d) Robogate 904 at MC km 2+175; (e) Robogate 905 at 1L-MC km 2+500; (f) master station. DS = Downstream; US = Upstream.

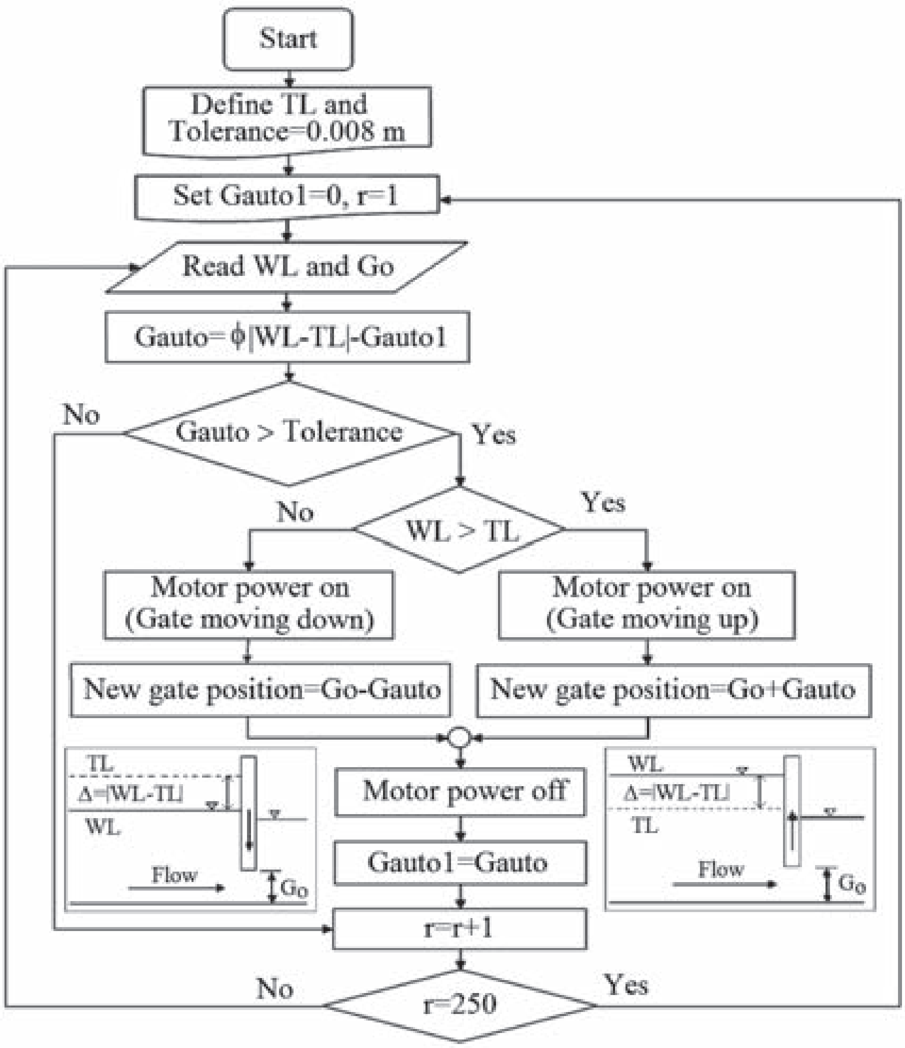

Figure 3 Upstream control algorithm of Robogate installed at cross regulators: WL = upstream water level; TL = target water level; G_0 = gate position; Gauto = calculated gate position adjustment value; Gauto1 = previous gate position adjustment value; r = sub-loop; ϕ = coefficient of automatic gate adjustment, equal to 1.0 in this study. (Sriwongsa and Vudhivanich, 2008)

Table 3 Coefficients C_1, C_2 and gate threshold elevation of 4 main regulators of Kamphaengsaen irrigation water delivery system.

Regulators	Threshold elevation (m msl)	C_1	C_2
MC head regulator at km 0+000	7.394	1.1418	-2.1586
MC cross regulator at km 0+725	8.012	0.4799	-0.1971
1L-MC head regulator at km 0+000	7.856	0.3384	-0.5998
1L-MC cross regulator at km 1+200	6.300	0.1516	-0.4056

msl =mean sea level.

measurement by water level sensor 2) the performance of the automatic upstream control algorithm 3) the reliability of measurement and 4) the control performance of the KPS CAS in automatic mode compared to manual operation.

RESULTS AND DISCUSSION

Accuracy of water level sensors

The accuracy of the water level measured by the floating-type potentiometer sensors was tested against the manual staff gauge measurement under field conditions. The water level readings from the sensor and staff gauge of the five Robogates were sampled and the differences between the sensors and manual readings were computed (Table 4). The probability distribution of the differences was normally distributed with almost a zero mean and 1.7 cm standard deviation by chi square test ($P > 0.01$). There was more than a 90% probability that the differences were distributed between -3 and 3 cm. The mean absolute difference was small (1.0–2.2 cm). The sensor readings showed very high correlation with the manual staff gauge measurement; R^2 was between 0.896 and 0.986, which showed that the water level measurement by the floating-type potentiometer sensor differed only by a very small amount from the staff gauge measurement.

Performance of automatic upstream control algorithm

The performance of the automatic upstream control algorithm as shown in Figure 3 was tested. The large amount of water level and gate opening data from Robogate 9021were recorded at 5 sec intervals in order to see how the upstream control algorithm worked under field conditions. The data consisting of over 20,200 records from four samplings were obtained for analysis as shown in Figures 4(a)–(d). There were seven cases where the upstream water level deviated from the target control water level and Robogate adjusted the gate automatically to maintain the target upstream water level. Three cases where the upstream water level dropped below the target level of 8.45 m msl and three cases where the upstream water level rose above the target water level are plotted in Figure 5 in order to show how Robogate 9021 worked in this unsteady state until the target upstream water levels were maintained. The number of gate

Table 4 Differences in water level measurement using floating-type potentiometer sensor compared to staff gauge measurements.

Robogate	Sensor	N	Average WL(m)	Absolute error			R^2
				Min. (m)	Mean (m)	Max. (m)	
901	US.WL	61	8.771	0.003	0.019	0.048	0.965
	DS.WL	61	8.529	0.002	0.010	0.024	0.986
902	US.WL	67	8.398	0	0.009	0.020	0.985
(9021)	DS.WL	67	8.265	0.003	0.022	0.059	0.927
(9022)	DS.WL	67	8.253	0	0.014	0.054	0.896
903	US.WL	67	6.895	0.001	0.014	0.059	0.976
	DS.WL	67	6.802	0.001	0.012	0.033	0.972
904	WL	60	7.685	0.001	0.009	0.026	0.962
905	WL	64	5.320	0.001	0.013	0.039	0.979

N = number of measurements; Max. = Maximum; Min. = Minimum; msl = mean sea level; WL = water level; US = upstream; DS = downstream.

adjustments and adjustment time periods from Figure 5 are summarized in Table 5. There were 4–12 gate adjustments until the upstream water level was maintained at the target level and the time periods for gate adjustments were between 310 and 780 sec. Vudhivanich and Sriwongsa (2011) reported that the gate adjustment periods were 120–480 sec on the laboratory experiment in the canal automation model. Case 4 of Figure 5 was the worst case when the upstream water level started to exceed the target water level of 8.45 m msl; Robogate increased the gate opening which resulted in lowering the upstream water level below the target level and Robogate had to decrease the gate opening to increase the upstream water level. This situation was repeated back and

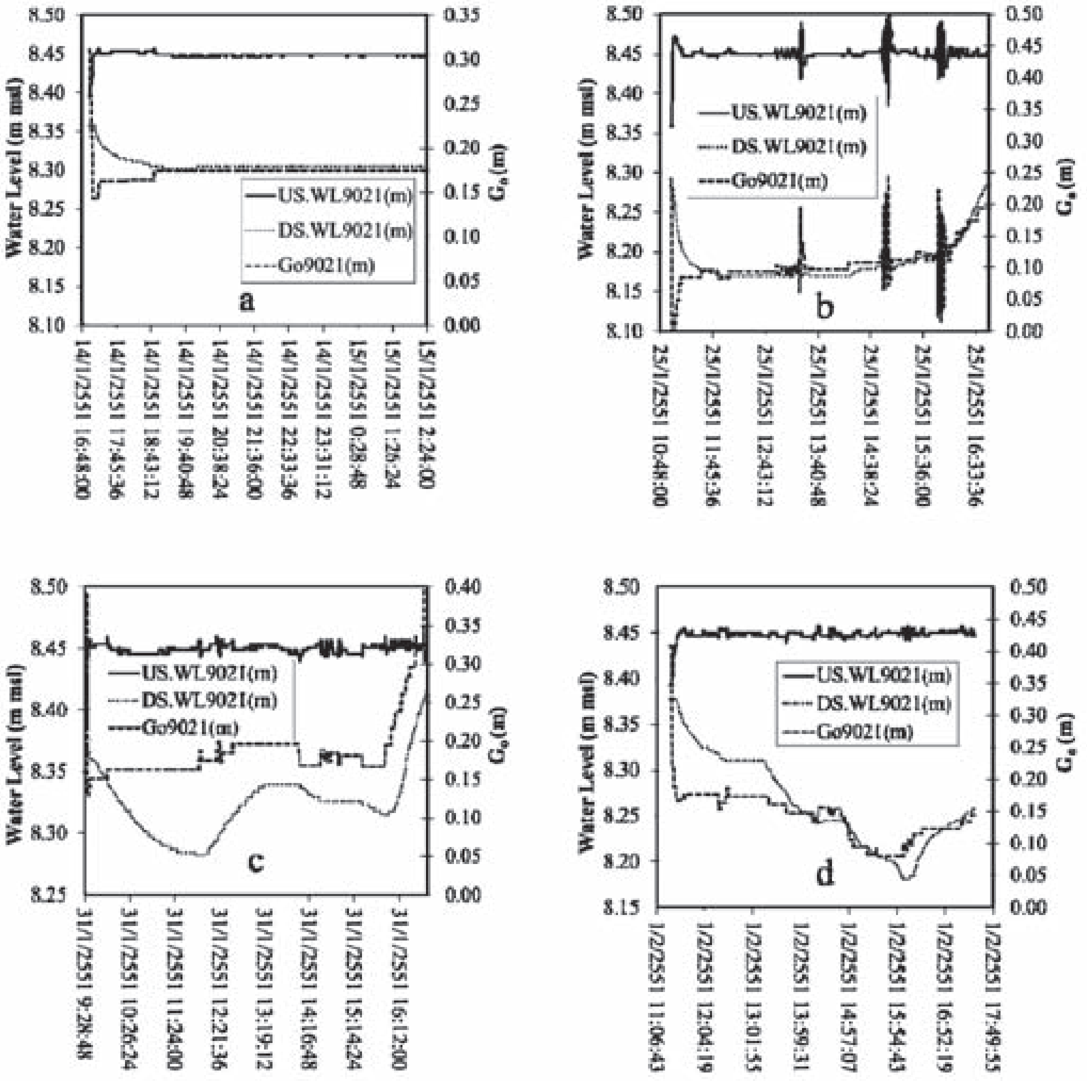

Figure 4 Upstream water level control characteristics of Robogate 9021 recorded at 5 sec intervals: (a) 6,621 records on 14 Jan 2008; (b) 4,282 records on 25 Jan 2008; (c) 5,704 records on 31 Jan 2008; (d) 4,383 records on 1 Feb 2008.(G_o = gate opening; WL = water level; US = upstream; DS = downstream; msl = mean sea level)

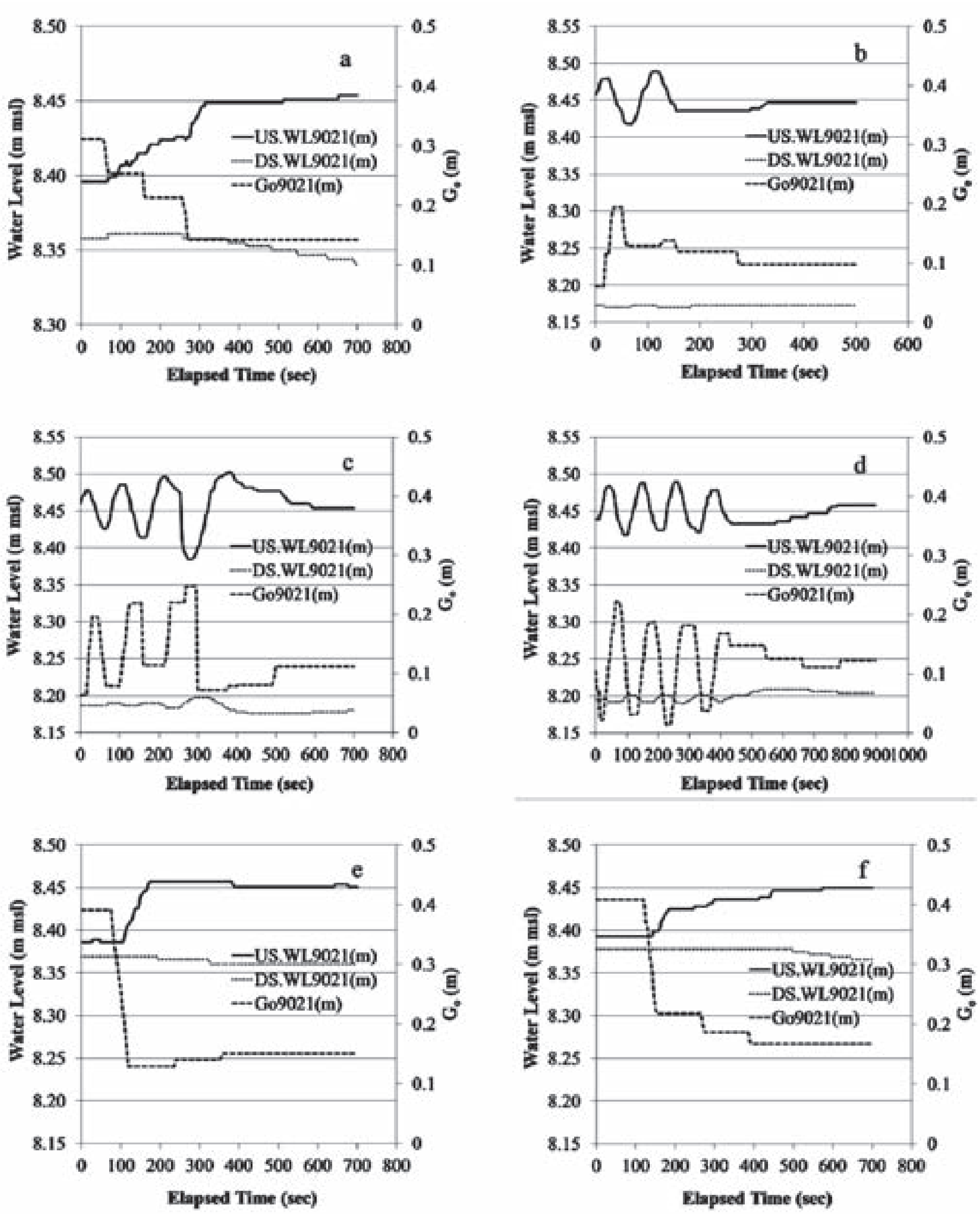

Figure 5 Enlargement of Figure 4 to show the performance of Robogate 9021 to maintain the upstream target water level: (a) case 1 US.WL < TL; (b) case 2 US.WL > TL; (c) case 3 US.WL > TL; (4) case 4 US.WL > TL; (5) US.WL < TL; (6) US.WL < TL. (G_o = gate opening; WL = water level; US = upstream; DS = downstream; TL = target level; msl = mean sea level)

forth five times before the upstream target water level was maintained at the target. This oscillation can take place when the coefficient (ϕ) of the linear proportional control algorithm is not appropriate. This is one disadvantage of the control algorithm used in Robogate. To reduce this effect, further study is needed to find an appropriate coefficient.

Reliability of measurement

The functions of Robogate are to measure the water levels and gate positions and to transmit the data to the datalogger at the master station via CB communication radio every 30 min. There were three main factors that could reduce Robogate's capability to satisfactorily complete these functions—interference in radio communication, electricity failure and equipment failure. The data recorded in the datalogger at the master station from 10 October 2006 to 1 June 2008 were analyzed in order to determine the percentage of missing data (Table 6). The percentage of missing data ranged between 14.0 and 22.3% and averaged 17.3. From this analysis, it can be concluded that the KPS CAS had 82.7% reliability of measurement which was considered quite acceptable.

Control performance of Kamphaengsaen canal automation system

The KPS CAS was tested for 600 d during the period from 10 October 2006 to 1 June 2008. The system was operated in manual mode from 10 October 2006 to 3 January 2008 and in automatic mode from 4 January to 1 June 2008. The flow characteristics including the upstream and downstream water levels, gate openings and discharges of the regulators controlled by Robogates 901–903 are plotted in Figure 6. The tail water levels monitored by Robogates 904 and 905 are also plotted in Figure 6. It can be seen that the automatic mode operation could control the upstream water level at the target with a much

Table 5 Gate adjustment statistics of Robogate 9021 to maintain the target upstream water level.

Case	Date	Time (hr:min:sec)	No. of gate adjustments	Adjusted time period (sec)
1	14 Jan 06	17:00:14–17:13:10	4	310
2	25 Jan 06	13:21:30–13:29:50	7	270
3	25 Jan 06	14:52:35–15:04:15	10	495
4	25 Jan 06	15:15:40–16:06:35	12	780
5	31 Jan 06	19:30:10–19:41:50	4	355
6	1 Feb 06	11:22:30–11:34:10	4	385

Table 6 Analysis of measurement reliability of Robogate.

Robogate	Number of recorded data			Missing data (%)	Reliability of measurement (%)
	Theoretical	Actual	Missing		
901	28,752	23,194	5,558	19.3	80.7
902	28,752	24,728	4,024	14.0	86.0
903	28,752	24,470	4,282	14.9	85.1
904	28,752	22,350	6,402	22.3	77.7
905	28,752	24,127	4,625	16.1	83.9
			Average	17.3	82.7

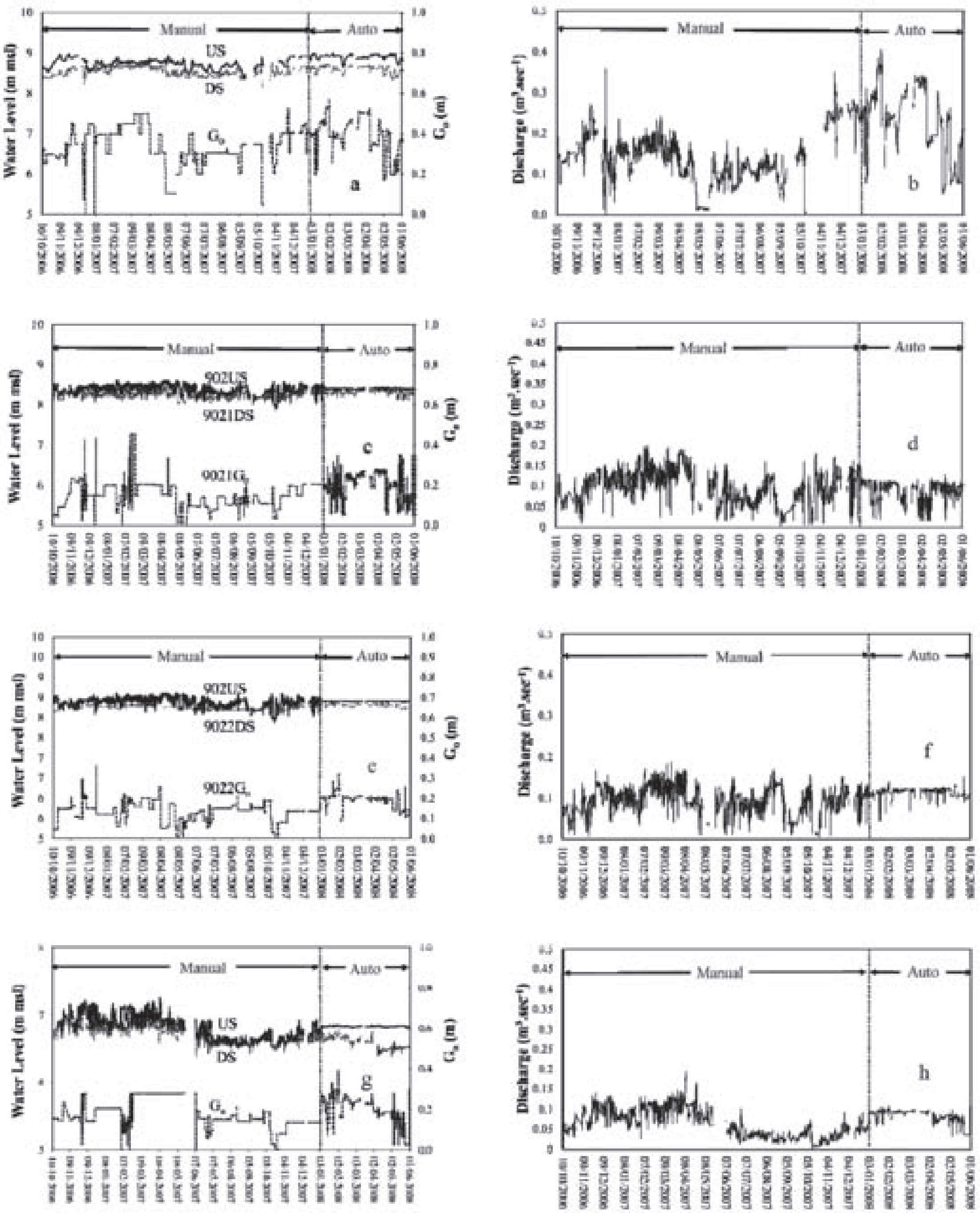

Figure 6 Flow characteristics of manual and automatic modes of operation recorded at different Robogates from 10 October 2006 to 1 June 2011: (a) water level and gate opening at Robogate 901; (b) discharge at Robogate 901; (c) water level and gate opening at Robogate 9021; (d) discharge at Robogate 9021; (e) water level and gate opening at Robogate 9022; (f) discharge at Robogate 9022; (g) water level and gate opening at Robogate 903; (h) discharge at Robogate 903; (i) water level at Robogate 904; (j) water level at Robogate 905. (Manual = Canal automation system set in manual operation mode; Auto = Canal automation system set in automatic operation mode; US=upstream; DS=downstream; G_o=gate opening.)

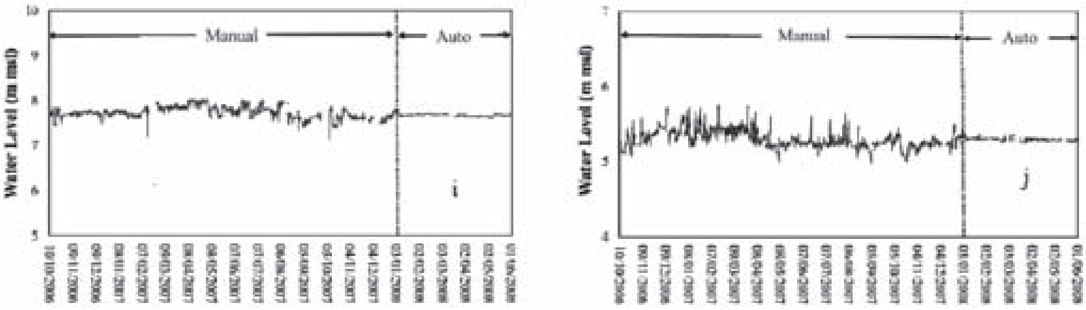

Figure 6 (Cont.)

smaller variation than the manual mode of operation as shown in Figures 6(c) and (g). This can be explained by the fact that when the KPS CAS operated in automatic mode, Robogate monitored and adjusted the gate every 0.5 sec. During this very short time period, the upstream water level would deviate from the target by only a small amount; therefore, only a small gate adjustment was needed each time to bring the water level back to the target level. This was in contrast to manual operation, where due to the limited number of staff, the gate could be adjusted only once every day or every two days and so a higher water level fluctuation could be expected. The discharge regulators controlled by Robogates 901 and 9022 showed similar results. The discharge at Robogate 9022 during automatic mode operation showed much smaller variation than that during manual operation mode. Consequently, the discharges at Robogates 9021 and 903 and the tail water level at Robogates 904 and 905 showed smaller variations in automatic mode.

Statistical analysis of the Robogate flow control parameters in manual and automatic operation modes from Figure 6 is shown in Table 7. The coefficient of variation (CV) of the upstream water level control by Robogates 9021 and 903 was in the range 0.002–0.003 in automatic mode which was a much smaller range than the CV in manual mode (0.014–0.026). There was no difference compared to the CV of discharge at Robogate 901 because of the high variation in the water requirements of the Kamphangsaen irrigation system during the experimental period under the manual and automatic modes of operation.

The performance of the Robogate to control the water level upstream of the regulators to meet the target water level was evaluated by the root mean square error (RMSE). The RMSE values of the target water level control in manual and automatic modes of operation are compared in Table 8. The range in the RMSE of the target water level control in automatic mode (0.009–0.013 m), was much smaller than the RMSE range in the manual mode (0.118–0.178 m), which showed that the automatic mode of operation could control the upstream water level much better than the manual mode. With smaller levels of water fluctuation at the cross regulators, the regulator could provide a more uniform discharge into the canal. For example, if the cross regulators could control the upstream water level within the target water level to ± 1 RMSE, the variation of discharge through the regulators could be estimated from the average flow characteristics during the test as shown in Table 9. A water level variation within ±1 RMSE from the target level could cause very high differential hydraulic head variation (Δh variation) for manual operation (64.7–120.4%), compared to the variation for automatic operation

Table 7 Comparison of statistics of the Robogate flow control parameters in manual and automatic modes.

Regulator	Flow control parameter	Manual mode operation					Automatic mode operation				
		Max.	Min.	Mean	SD	CV	Max.	Min.	Mean	SD	CV
901	Discharge ($m^3.s^{-1}$)	0.353	0.000	0.144	0.064	0.444	0.405	0.051	0.202	0.091	0.450
9021	US water level (m msl)	8.726	7.891	8.391	0.115	0.014	8.436	8.309	8.409	0.013	0.002
9022	Discharge ($m^3.sec^{-1}$)	0.263	0.000	0.094	0.040	0.426	0.152	0.000	0.115	0.012	0.104
903	US water level (m msl)	7.459	6.527	6.828	0.176	0.026	6.849	6.610	6.830	0.020	0.003
904	Tail water level (m msl)	8.058	6.305	7.640	0.824	0.108	7.756	7.621	7.681	0.022	0.003
905	Tail water level (m msl)	5.750	2.760	5.278	0.293	0.056	5.364	5.251	5.294	0.017	0.003

Max. = Maximum; Min. = Minimum; CV=coefficient of variation = SD/mean; US = Upstream; msl = mean sea level.

Table 8 Performance of Robogate for upstream water level control of cross regulators.

Robogate	Target water level (m msl)	RMSE (m)	
		Manual operation	Automatic operation
902(9021)	8.410	0.118	0.013
903	6.830	0.178	0.009

Root mean square error = RMSE = $\sqrt{\frac{(WL - TL)^2}{N}}$; msl = mean sea level.

(3.3–13.3%). High differential head variation resulted in high discharge variation (Q variation) with a range of 28.3–48.5% for manual operation compared to 1.6–6.4% for automatic operation. Therefore, it can be concluded that the KPS CAS in automatic mode can be useful in flow regulation and control under field conditions.

CONCLUSION

Various aspects of the field performance of the Kamphaengsaen canal automation system were tested on the Kasetsart University, Kaphaengsaen campus for 600 d during the period from 10 October 2006 to 1 June 2008. The results showed that water level measurement using a floating-type potentiometer sensor had a very small error compared to manual staff gauge measurement; the mean absolute error ranged between 0.11 and 0.27%. The automatic upstream control algorithm of Robogate 9021 was tested with recordings at 5 sec intervals of the water level

Table 9 Performance of canal automation system for discharge control.

Robogate	Operation mode	TL (m)	Average DS (m msl)	Δh (m)	RMSE (m)	Δh variation (%)	Q variation (%)
902(9021)	Manual	8.410	8.312	0.098	0.118	120.4	48.5
	Auto	8.410	8.312	0.098	0.013	13.3	6.4
902(9022)	Manual	8.410	8.292	0.118	0.118	100.0	41.4
	Auto	8.410	8.292	0.118	0.013	11.0	5.4
903	Manual	6.830	6.555	0.275	0.178	64.7	28.3
	Auto	6.830	6.555	0.275	0.009	3.3	1.6

TL = Target water level; msl = mean sea level; DS = Downstream; RMSE = Root mean square error; $\Delta h\ variation(\%) = 100\frac{RMSE}{\Delta h}$,

$$Q\ variation(\%) = 100\left(\sqrt{1+\frac{\Delta h\ variation}{100}}-1\right)$$

and gate position. More than 20,200 data records from four sample periods were obtained for the analysis. When the upstream water level deviated from the target water level, the gate was adjusted 4–12 times automatically before the upstream water level was maintained at the target level. The time period required for gate adjustment was 310–780 sec which was acceptable for field operation. The data recorded in the datalogger at the master station from 10 October 2006 to 1 June 2008 were analyzed to determine the reliability of measurement, which was found to be acceptable with a result of 82.7%. The automatic mode of operation was compared to manual operation. The results showed that the automatic mode of operation could control the target upstream water level with much smaller variation than the manual mode operation. The CV of the water level in automatic mode was much smaller than that in manual mode. The RMSE of the target water level control in automatic mode (0.009–0.013 m) was much smaller than the RMSE in manual mode (0.118–0.178 m). With smaller water level fluctuation at the cross regulators, the regulator could produce a more uniform discharge into the canal. Therefore, it can be concluded that the KPS CAS in automatic mode can be useful in flow regulation and control. However the appropriate coefficients for the linear proportional control algorithm should be investigated in order to improve the performance of Robogate and the canal automation system.

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