Controlling Spillway Gates of Dams Using Dynamic Fuzzy Control

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***Abstract*—**Controlling spillway gates of dams is a complex, nonlinear, non-stationary control process and is significantly affected by hydrological conditions which are not predictable beforehand. In this paper, control methods based on dynamic fuzzy control are proposed for the operation of spillway gates of dams during floods. The proposed methods are not only suitable for controlling spillway gates but also able to maintain target water level in order to prepare a draught. In the proposed methods, we use dynamic fuzzy control that the membership functions can be varied by changing environment conditions for keeping up the target water level, instead of conventional static fuzzy control. Simulation results demonstrate that the proposed methods based on dynamic fuzzy control produce an accurate and efficient solution for both of controlling spillway gates and maintaining target water level defined beforehand.

***Index Terms*—** control of spillway gates, dynamic fuzzy control, target water level

I. INTRODUCTION

The operation of dams is a control process that essentially manages the spillway gates in a dam to increase or decrease the released water [1]. In such a control system, positions of the spillway gates are usually regulated by human experts according to changing environment conditions. But the determination of the inflow hydrograph can be extremely difficult because the hydrological conditions have a nonlinear and probabilistic behavior. Because of the reason, construction of a precise model of controlling spillway gates based on the inflow and outflow hydrographs is very difficult.

Several methods and models have been proposed to achieve an efficient control of spillway gates of dams [2-5]. Can and Houck [2] developed a goal-programming model for the hourly operations of a multi-reservoir system. Oshimaa and Kosudaa [3] presented a distribution reservoir control approach with demand prediction using deterministic-chaos method. Liong et al. [4] applied a prediction tool based on neural networks to forecast water level at Dhaka(Bangladesh). Dervis Karaboga et al. [5] proposed a method of contolling spillway gates of dams based on a fuzzy logic controller using 25 fuzzy rules built by heuristics of human experts and optimized 15 fuzzy rules by Tabu Search algorithm [6]. The Dervis Karaboga's method have a characteristic which the water level of a dam always lowers to the minimum water level, so the water level can not be maintained at water level defined beforehand. But there is necessity for maintaining a certain water level to keep up the volume of reservoir water in order to prepare a drought.

In this paper, we propose an effective method for controlling spillway gates having a function of maintaining target water level by modifying the Dervis Karaboga's method. In the proposed method, we use a dynamic fuzzy control instead of conventional static fuzzy control, to control spillway gates and to maintain target water level even in a situation changing rapidly. In order to evaluate the performance of the proposed method, we compare the results of our proposed method with the results of Dervis Karaboga's method by experiment in simulation environments.

II. FUZZY CONTROL OF SPILLWAY GATES

The input variables for the fuzzy control system are water level(H) and the change in the water level(dH). The output variable of the system is the gate opening(d). Thus, the outflow rate of a dam is controlled by the gate opening which is controlled by the fuzzy control system. For H, dH, and d, the normalization intervals are selected as [118 (top of active pool, m), 127 (maximum pool elevation allowed, m)], [-1 (maximum water level falling, m), 1 (maximum water level rising, m)], and [0 (fully closed gates, m), 12 (fully open gates, m)], respectively.

For the fuzzy control system, rule base is constituted based on human expert experience as shown in Table 1(V: Very, N: Negative, P: Positive, L: Low, M: Middle, H: High, B: Big, S: Small, ZE: Zero). The membership functions are also constituted based on human expert experience as show in Fig. 1. But in this paper, we

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proposed two methods that the membership functions used for the water level(H) are changing in proportional to the value of target water level(t).

Table 1 Fuzzy rule base

dH H	NB	NS	ZE	PS	PB
VL	VL	VL	VL	VL	VL
L	L	L	L	L	L
M	M	M	M	M	M
H	H	H	H	H	H
VH	VH	VH	VH	VH	VH

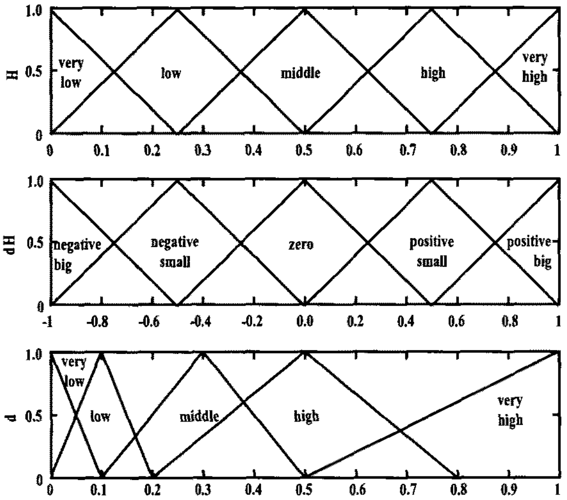


Fig. 1 Membership functions for fuzzy variables

A. Common Processes of the Two Proposed Methods

In the two proposed methods, fuzzy input variables for the change in the water level(dH) are divided into 5 stages of Negative Big(NB), Negative Small(NS), Zero(ZE), Positive Small(PS), and Positive Big(PB). The calculation method of the input variables for the change in the water level(dH) is as follows.

$$OutflowCapacity = GateHeight \times Outflow \tag{1}$$

$$ChangeOfCapacity = (InflowCapacity - OutflowCapacity) \times 3,600 \tag{2}$$

$$CapacityAfterChange = CurrentCapacity + ChangeOfCapacity \tag{3}$$

$$dH = WaterLevelByCapacityAfterChange - CurrentWaterLevel \tag{4}$$

Outflow is defined as $700\,m^3/s$ by 1m change of a spillway gate and 3,600 is multiplied in Eq. (2) because reservoir capacities of inflow and outflow are measured by a unit of second but current reservoir capacity and change of reservoir capacity are measured by a unit of hour. Water level by reservoir capacity is calculated using Table 2. The data in Table 2 are come from a real dam called Catalan Dam and we used the data in simulation environment for experiments [7].

Table 2 Water level and reservoir capacity relationship of Catalan Dam

Water Level(m)	Reservoir Capacity($10^6 m^3$)
112.5	1,250
115.0	1,420
117.5	1,560
120.0	1,735
122.5	1,900
125.0	2,120
127.5	2,310
130.0	2,550

In order to calculate the output value for controlling spillway gates, we used conventional rule base of 25 rules as shown in Table 1. In the calculation process using fuzzy logic, we used Mamdani's Max-Min inference method and Center of Sum method as a defuzzification method[8]. In the simulation experiment, the final defuzzification value($\bar{z}$) is multiplied by 0 in order to close spillway gates completely in case of only Very Low(VL), because Center of Sum method always yields defuzzification values larger than 0 in rules having consequent of Very Low(VL).

B. The First Proposed Method

The first proposed method is that the widths of the membership functions used for the water level(H) are to be maintained but the number of the membership functions is to be decreased in proportional to the target water level(t). The specific description of the first proposed method is shown in Fig. 2.

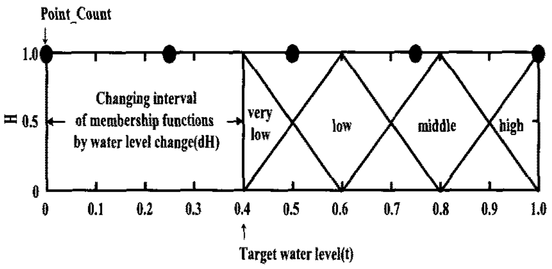


Fig. 2 Membership functions of the first proposed method for the water level(H)

At first, we should determine the number of fuzzy membership functions in the range from target water level(t) to the maximum water level. For the determination of the number of membership functions, if the Eq. (5) is satisfied, an internal variable, count is increase by 1 every 12 minutes and then the width of each membership functions, Step is calculated by Eq. (6) every 1 hour. The number of membership functions is determined by the variable Step.

$$Target\_Water\_Level \leq Point\_Count \qquad (5)$$

$$Step = (1 - Target\_Water\_Level) / Count \qquad (6)$$

If there is no change in capacity of inflow, the position of target water level is maintained at the same position and if change in capacity of inflow occurs, the position of target water level moves according to the amount of the change.

C. The Second Proposed Method

The second proposed method is that the number of the membership functions used for the water level(H) is to be maintained but the widths of the membership functions are to be narrow in proportional to the target water level(t). The specific description of the second proposed method is shown in Fig. 3.

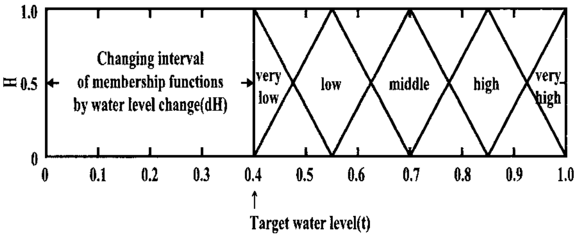


Fig. 3 Membership functions of the second proposed method for the water level(H)

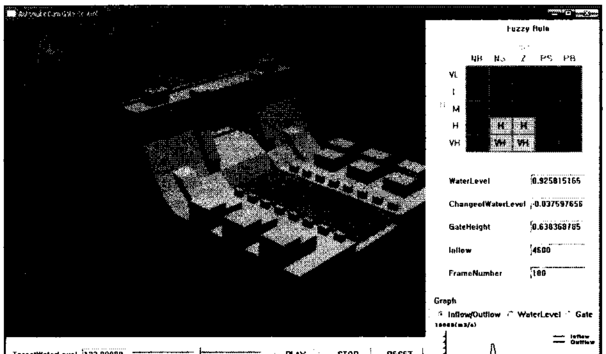
At first, we should determine the width of fuzzy membership functions so as to include all five membership functions in the range from target water level(t) to the maximum water level. For the determination of the width of membership functions, Step is calculated by Eq. (7) every 1 hour. The variable Step is used for determine the width of membership functions. The rest of the process is same as the first proposed method and is explained in next section more specifically.

$$Step = (1 - Target\_Water\_Level) / 4 \qquad (7)$$

III. EXPERIMENTAL RESULTS AND ANALYSIS

We implemented a simulation program using VC++ 6.0 for three kinds of experiments with conditions of same inflow pattern data and target water level of 122m as shown in Fig. 4. The only difference in the three experiments is the initial water level of a dam. 'Prop#1' and 'Prop#2' in the following figures denote the first and the second proposed method, respectively.

The first experiment is performed by the initial water level of 118m(low water level) and three graphs of the simulation results are shown in Fig. 5, Fig. 6, and Fig. 7. We can see that the gate of our proposed methods does not open until the water level reaches at the target water level, but in Dervis Karaboga's method, gate opens from the beginning. Because of this fact, the water levels of our proposed methods go up to the target water level rapidly but the water level of Dervis Karaboga's method goes up slowly at the beginning. In the interim interval of the diverse inflow change, there is no big difference between our proposed methods and Dervis Karaboga's method. In the last interval that inflow is decreasing, our proposed methods show that the water level converges to the target water level, but Dervis Karaboga's method shows that the water level lowers to the minimum water level.



WaterLevel 0.925815165
ChangeofWaterLevel -0.037597656
GateHeight 0.638368785
Inflow 4600
FrameNumber 180
TargetWaterLevel 122.00000
CurrentWaterLevel 126.29473
CurrentGateHeight 7.6604251

Fig. 4 The implemented simulation program

As shown in the Fig. 6 and Fig. 7, we can see that the second proposed method is better than the first proposed method because the second proposed method shows smooth change of outflow and smooth control of spillway gates, while the first proposed method shows abrupt change of outflow and control of spillway gates. This phenomenon seems to be caused by the variation of the number of fuzzy membership functions according to change in water level.

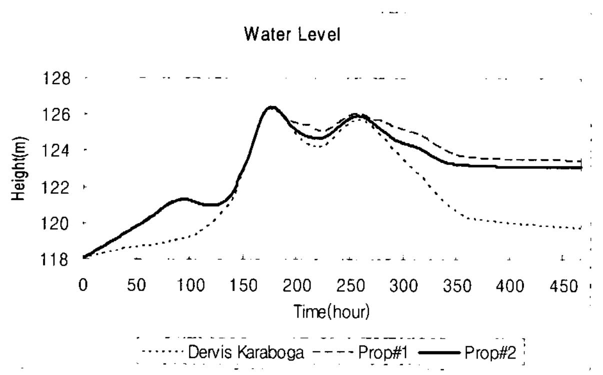


Fig. 5 Change in the water level in the first experiment

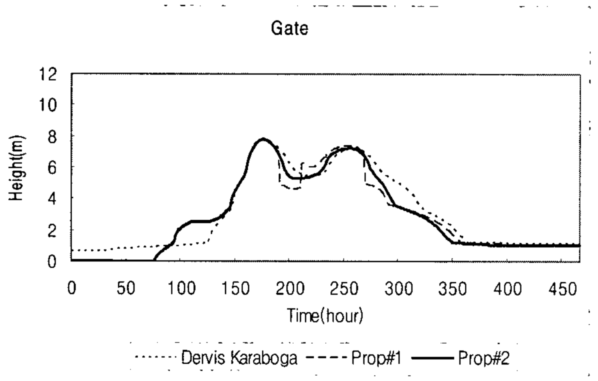


Fig. 6 Change in height of the gate in the first experiment

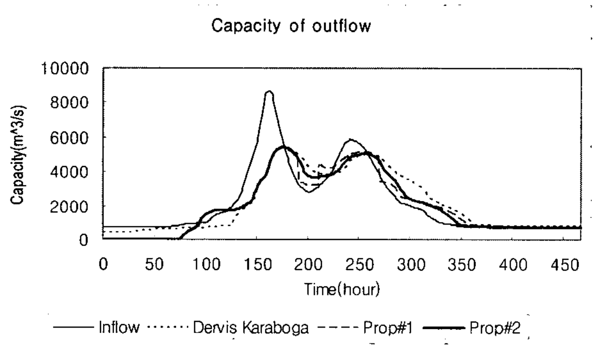


Fig. 7 Change in the capacity of outflow in the first experiment

The second experiment is performed by the initial water level of 122m(target water level) and three graphs of the simulation results are shown in Fig. 8, Fig. 9, and Fig. 10. We can see that the water levels of our proposed methods go over the target water level for a moment but the water level converges to the target water level immediately, while the water level of Dervis Karaboga's method always goes under the target water level because capacity of inflow is not much at the beginning. After then, if the capacity of inflow is come steady, our proposed methods show that the water level converges to the target water level, but Dervis Karaboga's method shows that the water level lowers to the minimum water level like the first experiment. We can see that the second proposed method is better than the first proposed method because of the same reason in the first experiment.

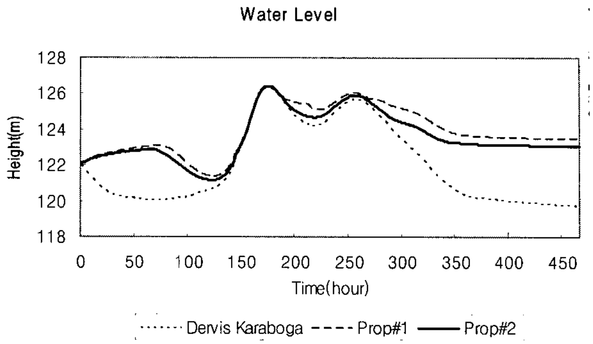


Fig. 8 Change in the water level in the second experiment

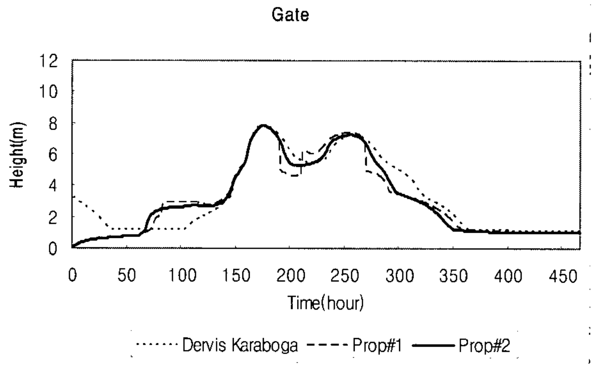


Fig. 9 Change in height of the gate in the second experiment

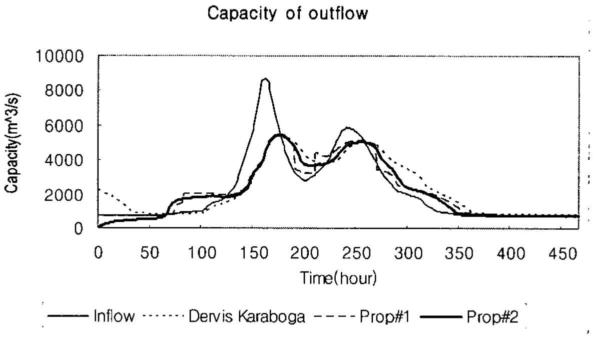


Fig. 10 Change in the capacity of outflow in the second experiment

The third experiment is performed by the initial water level of 125m(high water level) and three graphs of the simulation results are shown in Fig. 11, Fig. 12, and Fig. 13. We can see that the water levels of all of three methods go down to the target water level at the beginning because the current water level is higher than the target water level, but the water levels of our proposed method do not lower after reaching the target water level, while the water level of Dervis Karaboga's method continues to lower under the target water level. After then, the changes of all three methods are same as before.

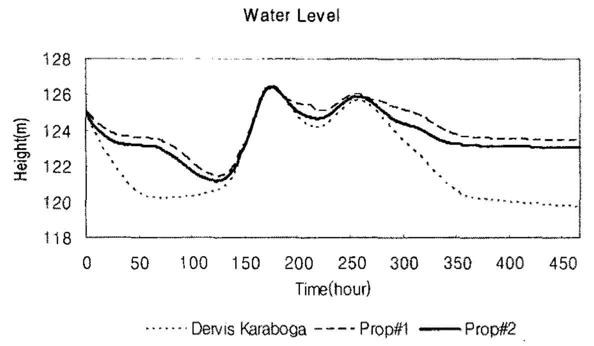


Fig. 11 Change in the water level in the third experiment

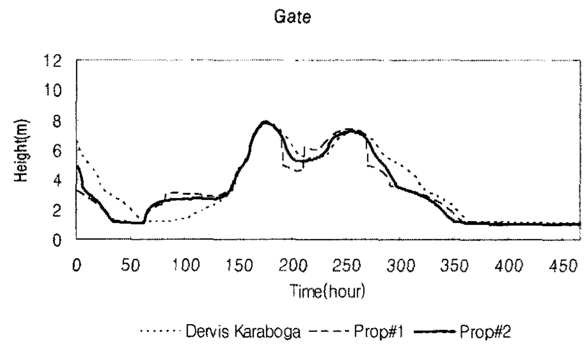


Fig. 12 Change in height of the gate in the third experiment

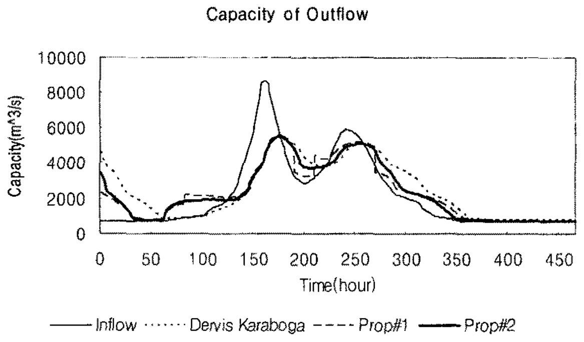


Fig. 13 Change in the capacity of outflow in the third experiment

IV. CONCLUSIONS

In order to control spillway gates of dams in the situation of rapid change in capacity of inflow or steady state in capacity of inflow and also in order to preserve the reservoir capacity for preparing a drought, it is necessary to devise a control system having not only functions for controlling spillway gates but also functions for maintaining the water level at a certain level. In this paper, we proposed two control methods based on dynamic fuzzy logic for the operation of spillway gates of dams not only suitable for controlling gates but also able to maintain target water level to solve such a problem. We can see that the proposed methods based on dynamic fuzzy logic produce an accurate and efficient solution for both of controlling spillway gates and maintaining the target water level defined beforehand through three kinds of simulation experiments, and also we can see the second proposed method shows better performance than the first proposed method in control of gate and capacity of outflow.

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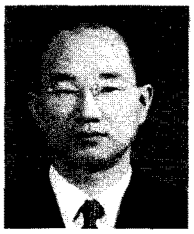

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