BUILDING AN INTELLIGENT RESERVOIR OPERATION DECISION SUPPORT SYSTEM FOR FLOOD AND SEDIMENTATION CONTROL

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Abstract

This study has constructed a window-based intelligent decision support system, including six modules: reservoir operation database query, typhoon flood pattern forecast, adaptive water pre-release operation strategy for hydroelectric generation, real-time reservoir rainfall-runoff forecast, reservoir sedimentation sluicing analysis, and water supply risk analysis. The adaptive water pre-release operation strategy for hydroelectric power generation module could suggest the pre-release water level before coming of typhoons and applied the fast elitist non-dominated sorting genetic algorithm (NSGA-II) to search the hydroelectric power generation operation during recession periods. The real-time reservoir rainfall-runoff forecast module applied the Back-Propagation Neural Network (BPNN) to build the rainfall-runoff models for forecasting one to five-hour-ahead reservoir inflow. The sedimentation sluicing analysis and the water supply risk analysis modules have been built based on the twelve typhoons with density flow reaching the dam. The density flow velocity and its travel time to reach the dam is estimated according to the statistics of twelve typhoons, which suggests the threshold of the density flow to reach the dam can be set as 1500 cms. The water supply risk analysis module can provide a risk analysis of stable water supply in downstream areas based on the results of the sedimentation sluicing analysis.

Keywords: Intelligent Decision Support Systems; Non-dominated Sorting Genetic Algorithm; Back-Propagation Neural Network; Reservoir Flood Control

1. INTRODUCTION

The Shihmen Reservoir, located upstream of the Tahan River, satisfies multiple purposes of irrigation, industrial and domestic water uses, flood control, hydroelectric power generation, and recreation. However, the socio-economic development in the Taoyuan area requires a fast turnover of reservoir water in about four or five times a year for satisfying various water users. Besides, the increasing trends of high intensive and long-duration rainfalls brought by typhoons and storms have notoriously resulted in soil erosion of the catchment area and reduced the reservoir storage capacity, which has made tremendous impacts on the livelihoods of residents. In order to achieve flood prevention, conduct anti-silting control and stabilize water supply, it is necessary for the

Shihmen Reservoir to operate for sedimentation control and to fully consider the risk of stable water supply as well as flood control.

Given the large number of high-risk situations as well as the extremely high costs in terms of casualties and damages involved in flooding, the implementation of flood control aimed at its reduction becomes essential from a holistic view of the problem. The main purpose of this study is to establish an intelligent real-time reservoir operation model for flood control to ensure reservoir safety and store floodwaters for future use. The intelligent model includes the fast elitist non-dominated sorting genetic algorithm (NSGA-II) to search the hydroelectric power generation operation and the Back-Propagation Neural Network (BPNN) to build the rainfall-runoff models for forecasting one to five-hour-ahead reservoir inflow.

Artificial intelligence tools such as the artificial neural network (ANN), genetic algorithms, and fuzzy logic approaches have been proven to be efficient in a variety of problems when applied individually or in combination with each other. In the last decade, the development of optimal reservoir operation methodologies for flood control has been very active (Chang, 2008; Chang and Chang, 2009; Aboualebi et al., 2015). ANNs are known as flexible modeling tools with capabilities of learning the mathematical mapping between input and output variables of nonlinear systems and have been quite successfully used for different hydrosystem and reservoir problems (Menezes and Barreto, 2008; Chang et al., 2010; Lin et al., 2010; Jiang and Song, 2011; Chang and Tsai, 2016).

2. METHODOLOGIES

2.1 Non-dominated Sorting Genetic Algorithm

The non-dominated sorting genetic algorithm (NSGA) is developed and is improved to the fast elitist non-dominated sorting genetic algorithm (NSGA-II) by Deb et al. (2002). The NSGA-II algorithm consists of five operators: initialization, fast non-dominated sorting, crossover, mutation and the elitist crowded comparison operator. The NSGA-II uses the non-dominated sorting and ranking selection with the crowded comparison operator.

2.2 Back Propagation Neural Network

The back propagation neural network (BPNN) is the most popular and widely used. It is a multilayer feedforward artificial neural network, and consists of an input layer, one or more hidden layers and an output layer. In the training phase, the synaptic weights of the feedforward network are adjusted by using supervised learning to minimize the error between the network output and the desired output.

3. INTELLIGENT RESERVOIR OPERATION DECISION SUPPORT SYSTEM

This study has constructed a window-based intelligent reservoir operation decision support system, including six modules: reservoir operation database query, typhoon flood pattern forecast, adaptive water pre-release operation strategy for hydroelectric power generation, real-time reservoir rainfall-runoff forecast, reservoir sedimentation sluicing analysis, and water supply risk analysis. The main screen of the system is designed for accessing the functions of updating the newest data and executing six modules, shown in Fig.1. The system can allow users to set update frequency (e.g. 15, 30, 60 minutes) and update the newest data automatically.

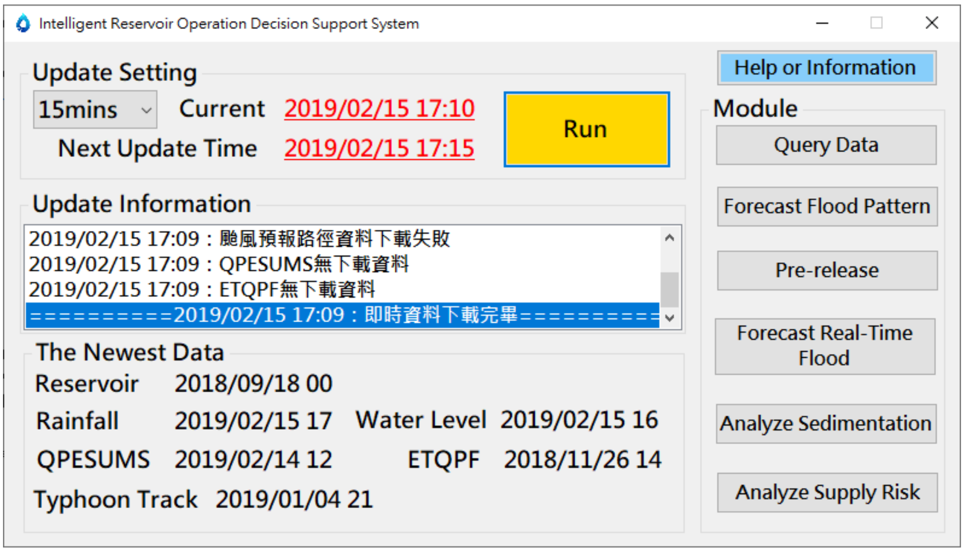

Fig.1 The main screen of the intelligent reservoir operation decision support system

3.1 Reservoir operation database query

The reservoir operation database query module is designed as shown in Fig.2 and we keep updating the latest data in the database. This database includes the complete reservoir operation hourly data (water level, storage capacity, inflow, outflow of each gate), hourly rainfall data (10 rainfall stations), hourly discharge data (5 flow stations) etc. The database has accumulated the reservoir operation data with a total of 111 typhoons and 5 rainstorms. For those of missing or mistakenly data, this module can automatically updated and amended to maintain the correctness of the information and integrity to provide a more stable and reliable source for decision support systems. This module provides users with two query options: choose the specific typhoon event or input the desired period and shows the results of query with tables and charts.

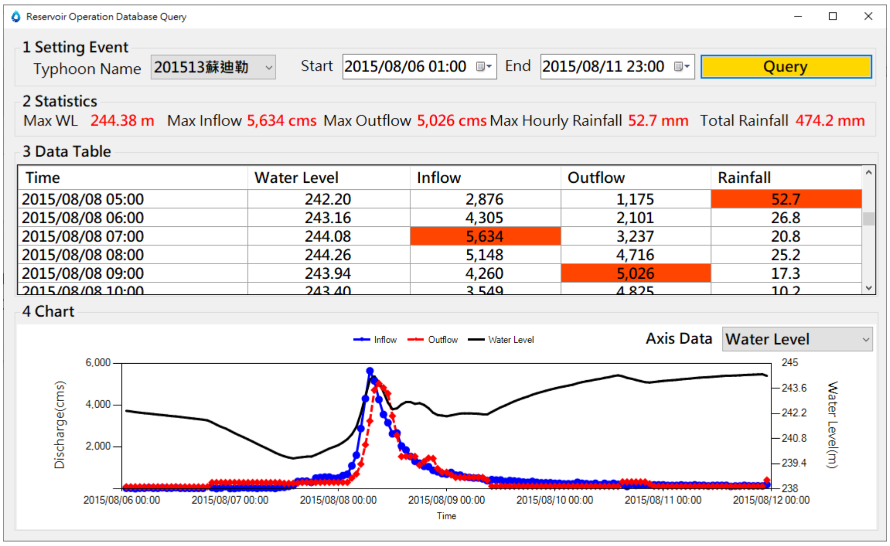

Fig.2 The diaglog box of the reservoir operation database query

3.2 Typhoon flood pattern forecast

This study used the self-organizing map (SOM) to classify the track of typhoons and to build forecast models for estimating the hydrograph of reservoir inflow during typhoon periods. Typhoon flood pattern forecast module uses the total rainfall amount forecasted by the Central Weather Bureau to synthesize the whole flow pattern before a typhoon affects the reservoir inflow to grasp its trends. The estimated hydrograph of reservoir inflow during 2015 SOUDELOR typhoon period is shown in Fig.3.

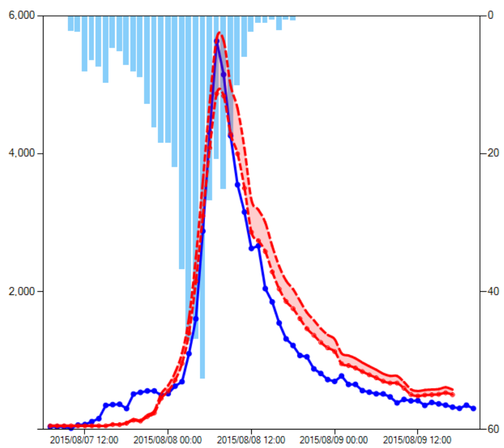

Fig.3 The estimated hydrograph of reservoir inflow during 2015 SOUDELOR typhoon period

3.3 Adaptive water pre-release operation strategy for hydroelectric generation

The "Adaptive water pre-realse operation" module can automatically suggest the pre-release water level during the period during the coming of typhoons and applied the NSGA-II to search the power generation operation during recession periods. The multi-objective reservoir operation with respect to four goals (maximum hydropower generation, maximum flood reduction rate, maximum water storage and minimum number of operations) The multi-objective optimal results (shown in Table 1) show that the NSGA-II results have similar power generation benefits as the historical operation, and the final reservoir water level can reach 244 m at the end of operation for future water resources management.

Table 1 The multi-objective optimal results during recession periods

Typhoon	Historical Operation			NSGA-II		
	Hydropower (10^4 W)	Final water level (m)	no. of operation	Hydropower (10^4 W)	Final water level (m)	no. of operation
2013Suli	576.97	239.64	7	576.97	243.99	6
2013Trami	765.08	243.16	13	765.05	243.99	3
2013Fitow	500.39	243.46	8	529.92	244.01	4
2014Matmo	524.06	241.96	8	598.55	244.00	2

3.4 Real-time reservoir rainfall-runoff forecast

This module adapts BPNN (shown in Fig.4) for the rainfall-runoff model construction. The time delay relationship between rainfall and runoff is calculate by the river flow direction and DEM data. The Shimen Reservoir catchment area can be divided into three areas, shown in Fig.5. As shown in the partition, the Catchment 1 rainfall delay is 2 hours; the Catchment 2 rainfall delay is 3 hours and the Catchment 3 rainfall delay is 4 hours. The model takes the upstream rainfall data and the reservoir inflow data as inputs, and apply the rainfall-runoff time delay of the sub-catchments, and selects different time interval prediction mode input as shown in Table 2.

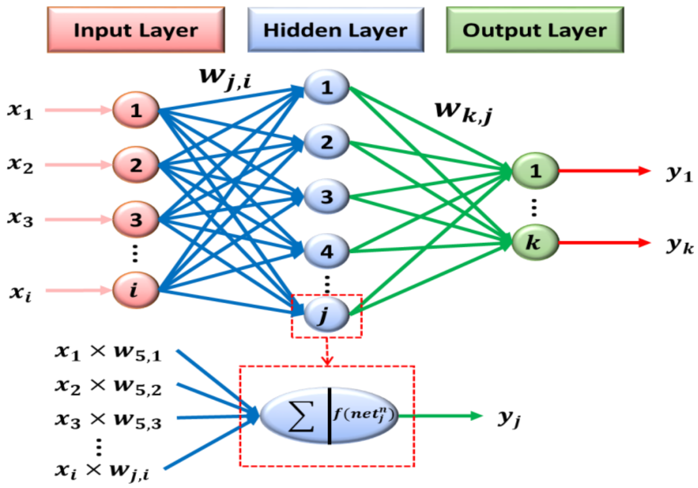

Fig.4 The structure of the rainfall-runoff BPNN model

The results are shown in Table 3. The R^2 of T+1~T+3 prediction results in the training and testing can aboe 0.90 , and T+4 and T+5 can above 0.78; The RMSE results are below 240 cms in T+1~T+3, and less than 360 cms in T+4 and T+5. The performance of the models are performance good.

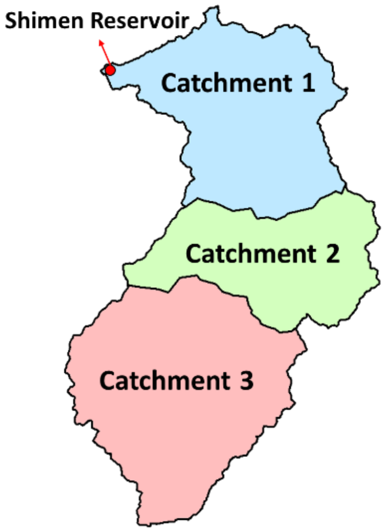

Fig.5 The sub-catchments of the Shihmen Reservoir.

Table 2 The neurons and inputs of the rainfall-runoff models

Model	No. of Neurons	No. of Input	Inputs			
			Rainfall of Catchment 1	Rainfall of Catchment 2	Rainfall of Catchment 3	Inflow
T+1	4	4	T-1	T-2	T-3	T
T+2	4	3	T	T-1	T-2	T
T+3	4	3	-	T	T-1	T
T+4	4	3	-	-	T	T
T+5	4	2	-	-	T	T

Table 3 Rainfall-runoff Model Results

Model	R^2			RMSE(cms)		
	Training	Validation	Testing	Training	Validation	Testing
T+1	0.98	0.96	0.97	163.15	137.95	127.44
T+2	0.96	0.90	0.94	232.75	219.78	178.24
T+3	0.94	0.79	0.90	312.08	320.14	237.22
T+4	0.90	0.67	0.85	392.15	410.20	293.35
T+5	0.84	0.57	0.78	479.38	472.07	353.93

3.5 Reservoir sedimentation sluicing analysis

The sediment sluicing strategy module has been refined based on the 12 typhoons events with density flow reaching the dam (as stated in the previous report of last year, the threshold for the density flow to reach the dam can be set as 1500cms). The regression formula of density flow in the Shihmen Reservoir is modified as function (1-1). After the modification, the MAE and RMSE of density flow velocity can achieve 0.34 m/s and 0.13m/s, respectively. It appears the density flow velocity and its travel time to reach the dam can be more accurately estimated as compared with the previous estimation, which can be a useful reference for reservoir operation.

$$U_f = 0.5733\sqrt{\frac{\rho_t - \rho_a}{\rho_a} \times gh} + 0.2262 \quad (1\text{-}1)$$

3.6 Water supply risk analysis

The sediment control strategy is proposed for calculating sediment release ratios of all water-release facilities, analyzing gravity current motion by simulation model, evaluating the sediment release operation conditions and providing the risk analysis of stable water supply in downstream areas.

4. CONCLUSION

This intelligent decision support system has been implemented to provide reservoir decision-makers with on-line relevant information during typhoon periods so that reservoir operators can obtain comprehensive typhoon information to carry out reservoir flood control operation.

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