USE OF ARTIFICIAL INTELLIGENCE METHODS FOR OPERATIVE CONTROL OF RIVER BASIN RUNOFF

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Abstract: The contribution outlines the possibilities of use of artificial intelligence methods at construction of controlling algorithms for operative control of river basin runoff. Using the example of Vranov - Znojmo cascade of reservoirs the article shows the achieved effects of controlling algorithms based on combination of non-linear programming and fuzzy regulators during the flood situation in August 2002.

Keywords: methods of artificial intelligence, neurone network, fuzzy-regulators, non-linear programming, controlling algorithms.

POUŽITÍ METOD UMĚLÉ INTELIGENCE PRO OPERATIVNÍ ŘÍZENÍ ODTOKU VODY Z POVODÍ (IN GERMAN)

Zusammenfassung: Der Beitrag deutet die Möglichkeiten der Anwendung der künstlichen Intelligenz bei einer Konstruktion der Steueralgorithmen zu einer operativen Steuerung des Wasserabfluss aus dem Flussgebiet an. Auf dem Beispiel der Staukaskade Vranov - Znojmo zeigt er die erreiche Wirkungen des an einer Kombination nichtlinearen Programmierung und fuzzy Regulierapparaten gegründeten Steueralgorithmus bei der Überschwämmungsituation im August 2002.

Schlüsselworte: Methoden der künstlichen Intelligenz, Neuronnetze, fuzzy Regulierapparate, Steueralgorithmen.

1. Introduction

When using methods of artificial intelligence (either neurone-regulators, fuzzy-regulators or various learning hybrid regulation systems) in operative control of water runoff from the river basin during the flood situation, the basic question is determination of controlling quantities course in relation with changing state of controlled system and possibly other input quantities (failures). This is true especially with dynamic systems, which work with significant delay. In the river basin with reservoirs the task is solved to find relation of controlling discharges or positions of individual reservoirs valves with temporal and spatial variation of precipitation above the river basin, river network discharge and filling individual reservoir. This relation can be found either in advance in known rainfall-runoff episodes and remembered or directly operatively solved during the flood passage. In both cases the methods of artificial intelligence, especially neurone-network and fuzzy regulators can play an important role.

2. Method

All input quantities, describing actual state of a system including courses of previous and future predicted rainfall and contingent other quantities needed for determination of controlling discharges (positions of valves) create a space of solution inputs.

In complicated multidimensional systems such as river basins with several reservoirs and a number of rainfall stations, the space of real solution inputs is quite large and for subjective action often not very well arranged. Therefore we can use the possibility to determine controlling quantities with classic optimisation algorithms (with chosen optimisation criterion, such as values of culmination discharges in chosen profiles of the river network which are consequently minimised.

The question occurs how to use methods of artificial intelligence for operative control of water runoff from the river basin during the flood passage? Several solutions are possible:

A. Substitution of real continuous space of solution inputs by discrete space and (in discrete points of this space) determination of the values of controlling quantities with optimisation. The positions of these discrete points in most cases will result from the types of the solved tasks and availability of solution fundaments. It is necessary, of course, to cover the input quantity space as evenly as possible with acceptable details.

For each discrete point of solution input space the values of controlling quantities are then calculated in advance. Such created examples of corresponding quantities can be written into input-output matrix, which describes the final behaviour of controlled system. This matrix can then be used as a training matrix and consequently can be trained for a neurone network (or any other learning hybrid system, etc.), which approximates the relation between discrete points of solution input space and calculated controlling discharges (or directly the positions of valves). For concrete actual inputs the neurone network very quickly determines the corresponding value of controlling quantities. The benefit of this process is the speed of the solution, which is necessary for operative control of fast changing state of the system (small and very small river basins) to ensure the control process in real time.

The described approach can be applied only in small river basins with one or more reservoirs, where intensity of rainfall above the river basin can be considered as constant and input quantities space is thus less complicated (Starý, Jacobsen, Dahl, 1993). Independent solution of lower parts of large river basins, where floods usually just pass, is similar (the influence of rainfall is neglected, etc.).

B. In this case we do not solve the relation: the discrete points of solution input space - corresponding controlling quantities (controlling runoff from the reservoirs) but in each time point, in which we change controlling quantities (control) we do the following: according to actual state of the system and valuation of future inflow (rainfall prediction), it means in actual discrete point of solution input space, we calculate controlling discharges values using optimising algorithm. Here we can use simulation model with optimised selection of parameters, where parameters are unknown controlling discharges. A part of this algorithm is a neurone-regulator, or fuzzy regulator which in relation with the value of controlling discharge (which is unknown) in each calculation temporal step directly quantifies the values of valve positions and thus enables the calculation of corresponding controlled discharges. The course of action setting and controlled quantities is then changed almost continuously. The mentioned quantification can be done in classic way as well using known relations from hydraulics. The advantage of using e.g. fuzzy regulation is in simplicity of solution, which is appreciated by everybody, who set up both types of regulators for the same purpose. For the successful results the quality software is necessary.

It is obvious that for this method every calculation for really large river basins with a number of reservoirs may need a great consumption of computer time. Especially if a continuous modelling of rainfall - runoff processes a part of controlling algorithms. Because the lag times of flow in a system (delays) are longer in medium size and large watersheds, the term of real time has a different dimension here. In The Ostravice River basin while using HYDROG Programme (Starý, 1991-2004) it was proved that it is satisfactory to change the positions of valves in a range of 1 to 3 hours during operative control in flood situation. Recent computer technology (at PC level) enables to shorten this time considerably.

Simplified description of such algorithm description (using fuzzy-regulator) was published e.g. in (Starý, 2001), (Starý, Doležal, 2003). In these articles not a direct application of neurone -network is used, but a different tool from the artificial intelligence field of research. A fuzzy regulator can be replaced by neurone-regulator though - a method is outlined.

C. This possibility is a combination of the methods described above. A neurone network (or hybrid network) is set from optimisation calculations (done in advance and trained afterwards) of controlling quantities in discrete points of solution input space with optimisation algorithms. A part of these algorithms are for instance fuzzy regulators, which in single temporal steps of the solution determine the setting of valves and afterwards enable quantifying the course of controlled outflows. With actual state of input quantities the trained neurone network then quickly determines the values of controlling discharges (or directly the valves positions). They are then quickly proceeded e.g. with fuzzy regulator. Application of this type of a task is described in (Drbal, 1999) and in (Nacházel, Starý, Zezulák, 2004) in 5.9 Chapter, in a part aimed at determination of final behaviour of a system with use of optimisation.

D. For determination of requisite courses of controlling quantities it is possible to use also other methods, e.g. to respect expert opinions and to use them for setting the neighbourhood function of fuzzy regulator or to determine limit (critical) values of discharge in chosen profiles of a river network and to calibrate corresponding neurone-fuzzy regulator with the use of specialised tuning. This approach is described also in (Drbal, 1999) and in (Nacházel, Starý, Zezulák, 2004)in 5.9. Chapter, in a part aimed at specialised tuning of a regulator.

Some of the mentioned possibilities of use of artificial intelligence were more or less verified in cited publications dealing with operative control of runoff from not only small river basin but urbanised river basins as well.

In the following text the results of controlling algorithm application based on combination of non-linear programming and fuzzy-regulation method are mentioned - the method described in **B**. It can be used for discharge control in lower parts of large watersheds, where with the help of another hydrological prediction model the future inflows into the system are estimated.

River network flow is solved as a one-dimensional flow. On the confluences is conserves the continuity of discharge only. Water flow in the river chanel is solved with help of kinematic wave approximation (Stephenson, Meadows, 1986). Open-chanel-flow is solved by continuity equation:

(1)

(2)

where *Q* is discharge, *A* is cross-sectional area , *x* is stream direction, *t* is time, *R* is hydraulic radius, *S* is bottom slope, *n* is Manning`s roughness coefficient.

The change of the open-chanel-flow in this silmplifying system is possible by reserviors only. Every water reservoir has its dynamic (transmission) qualities, which during the given reservoir volume filling *V(t)* at given time t and reservoir inflow *Q(t)* unequivocally determine the quantity of water reservoir outflow *Q(t).* The relation of these quantities can be described with the use of well known differential equation of the first order:

(3)

where *V(t)* is state values (quantity), *Q(t)* is an input quantity and *O(V(t))* is controlled quantity. Let's presume that initial values of reservoir inflow in time *t = 0*, i.e. *Q(0)* and reservoir filling *V (0),* i.e. initial solution conditions are determined by measurement. It is obvious that reservoir outflow in future time period τ depends (during a given time course of flow *Q(t))* on initial reservoir filling, on hydraulic quality of the spillway, on hydraulic quality of the bottom outlets and their opening. With these said conditions together with known prediction of reservoir water the controlled outflow depends on the position of regulation valves only. Their position could be in the future time period either constant or changing in time. With the help of appropriate set of above mentioned regulation valves positions it is possible to assign required dynamic (transmission) qualities to the reservoir.

Reservoir is considered according to the classic regulation theory as controlled object of regulation circuit with on-line control system. Reservoir inflow is considered faulty quantity
$z(t) = Q(t)$, required outflow from the reservoir as a controlling quantity $w(t)$, a real controlled outflow as controlled quantity $y(t)= O\ (V(t))$. Function objects are considered as action components and positions of the valves (spillways, bottom outlets, etc.) as action quantities, $u(t)$ is then an action setting. The aim of the manipulation is maximal decrease of reservoir culmination outflows, or decrease of culmination outflows in river profile further downstream. It is leading to the maximal flattening of the flood wave.

The construction of the controlling algorithm itself can be divided into two partial tasks. The first task is the choice of such regulator type, that would be able with given required controlling quantity course and continuously changing reservoir condition in discrete time steps gradually determine the values of action quantity changes (change of valves position) with adequate stability of regulation process. For this purpose the possibility of using fuzzy-regulation was verified. The type of proposed fuzzy regulator is proportionally integral (PI). Describing equation of this regulator is substituted by the rules contained in the rules base in this form:

if e=<hodnota> and e <hodnota> then u=<hodnota> **(4)**

Where e means regulation deviation between controlling and controlled outflow, Δe is change of regulation deviation, Δu is change of action setting (e.g. change in opening of bottom valves). Newly determined changes of action setting are thus given as a sum of action setting in previous time step and change of Δu. The Mamdani fuzzy interference system is used. Defuzzification is carried out with method of area center.

The second task is the necessity of determination of required quantity of controlling quantity $w(t)$. The task is solved for the future period with the help of simulation model with optimized parameter selection (Starý, 2001). The initial solution condition is always the actual filling of the reservoir and boundary condition is time behavior of predicted reservoir inflow. A parameter is an unknown value of controlling outflow, which is for simplicity considered as constant in the solved time period τ. For finding an optimal parameter value a simple grid method from non-linear programming was used. As an optimization criterion the value of culmination outflow from the reservoir was used, respectively in selected profile on the watercourse downstream. This criterion was minimized.

Numerical solving of the problem is discrete point simulation of continuous process. The percentage of opening the reservoir outlets is in each time step of the calculation Δt determined with the help of above described fuzzy regulator and time behavior of the total and partial water outflows is thus changing with the actual value of the parameter – required controlling outflow. For numerical solution of reservoir water outflow the Runge-Kutta method of the fourth order was used (Starý, 1990). For numerical solution of the water flow in river network the explicit differential method was used.

It is possible to choose any profile on the river under the reservoir and to carry out minimization of culmination flow there. In a given section of the river the stable flow is a condition at the initiation of operative control (the initial condition of the solution).

A process of operative control of system operation during the flood passage can be understood as a sequence of decision time points, in which the prediction of a future reservoir inflow for a period τ, mutually shifted with time step $\Delta\tau$, is repeatedly specified (prediction length is limiting time period Δτ). Measurement (calculation) determines instant reservoir filling. From the previous calculation we take corresponding discharges course in the river network and consequently with the help of simulation model with optimised choice of parameters (controlling quantities) we determine the values of controlling quantities valid for individual reservoir in the system. The output alternative from simulation model determines also time course of valve opening changes and thus the course of the total controlled outflow of water from the reservoir.

Algorithm which is based on adaptive principle described in details e.g. in (Nacházel, Starý, Zezulák, 2004) was programmed in MATLAB environment (MATLAB, 1984 – 2001). Water flow in the river network is solved with the help of kinematical wave approximation, (Stephenson Meadows, 1986), The basic equations of the reservoir are solved with Runge – Kutta Method of 4th order, (Starý, 1990).

The programme was used for simulation of operative control of water discharge through the cascade of the Vranov and Znojmo reservoirs on the Dyje River during the flood passage in August 2002.

3. Application

As a part of the solution the culmination discharge in the profile under the Znojmo Reservoir (last profile) was minimised (Fig. 1), (Starý, Doležal, 2003). The aim of the application was testing the algorithm function, although the ratio of retention capability of the both reservoirs is incomparable considering their volume. As a part of solution various lengths of prediction of water inflow into the system were tested: τ = 48 h, 72 h, 96 h and 120 h. For the testing the time interval between decision time points Δτ = 6 h was chosen (repeated calculation of controlling quantities – adaptation).

In Tab. 1 the values of culmination water discharges in Dyje/Hamry profiles and in last profile Dyje/Under the Znojmo Reservoir are given and achieved effects are evident. Illustrations of the solutions results for 120 h prediction length of water inflow into the reservoir are displayed in Fig. 2. In the series of figures a red line means pertinence to the Znojmo reservoir and blue line means pertinence to the Vranov. In the Fig. ”Partial and total outflow” thin line additionally means outflows from the bottom valve.

Table 1. Culmination discharges in Dyje/Hamry and last profiles

Inflow prediciton length [h]	Dyje/Hamry [$m^3.s^{-1}$]	Last profile [$m^3.s^{-1}$]
48	297.83	268.95
72	184.84	181.44
96	164.39	156.66
120	137.56	135.00

Figure 1. Cascade of the Vranov – Znojmo reservoirs

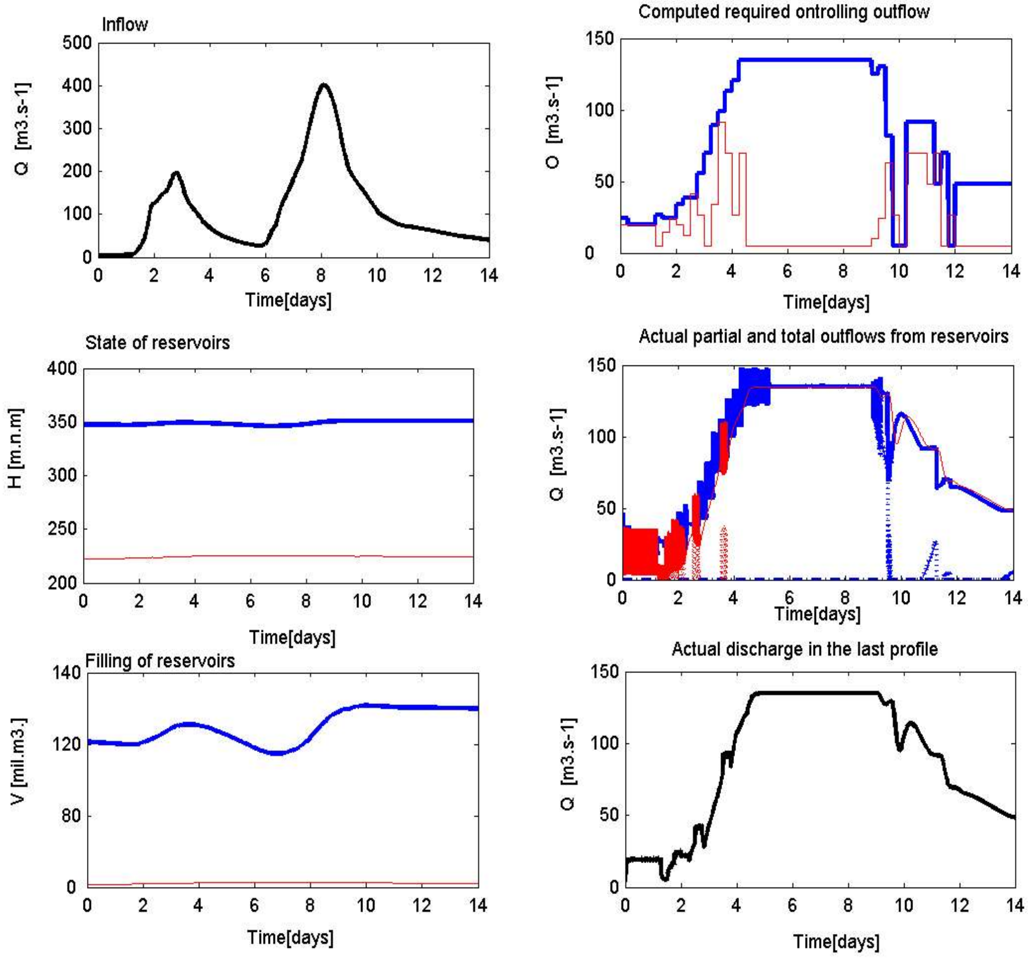

Figure 2. The solution results-the lenght of prediction 120h

4. Conclusion

Controlling algorithm is functional and gives very good results. It could be used for reservoirs which enable continuous remote valve control or which are equipped with programmed controlling microcomputer (fuzzy – regulator), which after determination of controlling quantity with central controlling computer enables the valves positions set up directly in controlling reservoir.

The certain vibration of reservoir outflow on an increasing branch of outflow can be removed with better setting up of a fuzzy - regulator. This was proved with additional experiments.

The influence of prediction length on lowering culmination water outflow from the reservoir is quite considerable. The positive effect had the prolongation of prediction from 48 h to 78 h., then the influence of prediction length started to decrease - it was significant though.

The chosen time interval between decision time points 6 h (repeated calculation of controlling quantities) we consider too long. It depends on the possibilities of issuing repeatedly specified values of predicted inflow into the reservoir. The decrease of the interval leads to better smoothing of controlled outflow from the reservoir. When using real (measured) predictions of water inflow into the system it is necessary to shorten this interval.

Algorithm required that the calculated controlling quantity course or set up of valves position in predicted period is constant. Numerical experiments showed that separation of these quantities to two and more (the number of unknown quantities increases proportionally and solution takes longer time) leads to smoothing of controlled outflows and to another decrease of culmination discharges. If the time interval between decision time points $\Delta\tau$ is shortened which is limited by the possibilities issuing operative predictions of water inflow into the reservoir, the similar effect is reached. Practice shows that hydrologic predictions of the discharges are often so inaccurate (accuracy of rain prediction) that used simplification we consider satisfactory.

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