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Hybrid optimization method for strategic control of water withdrawal from water reservoir with using support vector machines

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Abstract

The aim of strategic control is the effort to achieve optimal water resource management (water reservoir). Classic strategic control of water withdrawal from water reservoir are based mainly on the rules and rules curves, which are created by generalization of historical data of water inflows to the reservoirs and water demand. Discharge series are changing in the time due to expected climate change. It is necessary to looking for intelligent water withdrawal control, which will allow to react on these hydrological changes and contribute to the efficient use of accumulated water for ensure water demand. The paper will describe the algorithm based on adaptive control. The normal adaptive control required knowledge of the water flow medium-term prediction into the reservoir. The created algorithm of intelligent water withdrawal control does not require knowledge of hydrological predictions. This control method is based on a suitable combination optimization method with the Support vector machines method. The control algorithm is one of the possible measures to mitigate the negative impacts of droughts and water scarcity. The algorithm of adaptive control is applied to the control of water withdrawal from selected single-reservoir. The results are compared with usual rules for water withdrawal control.

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1. Introduction

Over the last few years we have been able to observe more frequent occurrence of hydrological extremes. Floods have become more frequent and droughts have become more severe. Expert studies in the field of climate science have been pointing out the occurrence of these extreme events for a long time now. As an example, the years 2011 and 2012 are worth mentioning, which in terms of hydrology were evaluated as extremely dry [1], as was also the last year 2015 [2]. It may be anticipated in the near future that such events will occur more often, and their negative effect will show a progressive trend.

In reality it is possible in the case of a sequence of occurrences of several droughts of longer duration that the storage function of some water sources may become jeopardized. Supposing that this threat will become reality and the water storage in water reservoirs will not be sufficient for operating them, a possible solution will lie in a change of the operating hydraulic structures. Such changes will be mainly based on alterations of the method of manipulation with controlled outflow. In an extreme case, if all other options of adaptation measures to ensure water management services are exhausted and when climate changes can no longer be solved by other means for their unfeasibility or disproportionate costs, it will be possible to extend the existing reservoirs by new ones.

The existing state of the active storage capacity control is sufficient but considering the climatic developments, it may soon become insufficient. Classical control of the storage capacity of water reservoirs is predominantly based on control rules [3] or rules curves [4]. The establishment of the above mentioned guidelines was influenced by the performance of the computer technology of that time, resulting in their considerable simplification. The guidelines are based on historical discharge series. The use of historical discharge series does not allow for the guidelines to respond adaptively to actual hydrological conditions. For this reason, the existing control guidelines may collide with limitations due to the changing hydrological conditions which cannot be included in the historical discharge series. Modern computer technology performance allows for the control methods used to be enhanced by the so called intelligent control methods. Intelligent control allows appropriate manipulation on hydraulic structures. Appropriate manipulation allows to prevent system failures such as lack of water supply, and also allows effective water management for hydropower purposes.

The commonly used control methods can be enhanced by intelligent control methods. The intelligent control method is based on the principle of adaptivity. An adaptive approach can respond to the continuously changing hydrological conditions. Such control usually requires the knowledge of prediction of the water flow into the reservoirs. In practice, it is possible to partly eliminate prediction inaccuracies using the adaptivity principle. Although the results of such control show a high potential [5], [6], [7] the successfulness of reservoir control is significantly dependent on the prediction accuracy. One of the possibilities of how to achieve greater success in reservoir control is to improve the prediction model. Another possibility is creating such intelligent control that would be able to respond dynamically to the changing hydrological conditions, and the control process itself would not be dependent on water flow predictions. Such algorithm of intelligent reservoir control not requiring the knowledge of water flow predictions is presented in this paper. This control method is based on an appropriate combination of the optimization model and the Support Vector Machines method [8]. Support Vector Machines (SVM) is a relatively new method belonging among the methods of machine learning. The proposed control algorithm may be used as a support tool for the water management control department, providing it with suitable support in the decision making process when controlling more complex systems with a number of reservoirs and considering a number of water management purposes. The presented control algorithm provides one of the possible measures for mitigating the negative impacts of droughts and water scarcity.

2. Methods

The hybrid optimization method for controlling the storage function of water reservoirs is based on the proposed algorithm combining the optimization model and the SVM method. Detailed descriptions of the optimization model and the SVM method are provided in the following text.

2.1. Optimization model

Put simply, the optimization model may be viewed as an optimization method with the aim to find an optimum solution. An optimum solution corresponds to the found optimum values which are unknown at the beginning of the solution, and which describe reservoir operations (water withdrawal from the reservoir) for several time steps (months) N ahead. It means that, based on the limiting conditions of the types of equations and inequalities, and based on the entered boundary and initial conditions, the chosen optimization method finds the desired values of the unknown, for which the chosen criterial function reaches the desired extreme. A detailed description of the mathematical model and the optimization model itself are described e.g. in [9]. The solution uses the optimization method of Differential Evolution.

The optimization model in a hybrid control method is used for finding optimum water withdrawal from reservoir $W_{T,\tau}$. Optimum monthly withdrawals $W_{T,\tau}$ are sought for each year $T = 1,2,...,M$, where M is the total number of years and for individual time steps $\tau = 1,2,..., N+L$, where $N+L$ is the number of time steps (months) of the discharge series of the mean monthly water flows into the reservoir $I_{T,\tau}$. For N, $N = 12 - L$ applies, and for L, $L \in \langle 1,11 \rangle$ applies. The number of years of the chosen time period M consists of the number of years of the historical monthly flows *HMF* and the number of years of the estimated discharge series. The estimated course of the discharge series expresses the changing hydrological conditions corresponding to the chosen climate change scenario *FMF* (future monthly flows). Individual years T are divided into two parts. The first part $\tau = 1,2,..., N$ represents the past and the second part $\tau = N+1,..., N+L$ represents the future. The time period $\tau = N+1,..., N+L$ is in the future only from the viewpoint of the optimization model, and may be designated as, e.g. a quasi-future period. For the quasi-future period we know the real values of mean monthly water flows into the reservoir. The first step of the quasi-future period in terms of real control will correspond to the real future period for which we will estimate the mean monthly water withdrawal from the reservoir $W_{T,\tau}$ and for which $T = M+1$ and $\tau = N+1$ apply. The withdrawal value from the reservoir $W_{T=M+1,\tau=N+1}$ is estimated (predicted) using the SVM method. The optimization model algorithm is shown in Fig. 1.

2.2. Support Vector Machines

The SVM method uses the advantages provided by effective kernel machine algorithms for finding the linear boundary while maintaining a highly complex non-linear function. One of the basic principles is the transfer of the given original entrance space into another, multidimensional one, where classes can be separated from each other linearly. By this approach the SVM method differs from other methods of machine learning, e.g. from the most diffuse method of artificial neural networks. Originally, SVM was focused on the classification of data points, later it was enhanced by the possibility of solving non-linear regression problems. At present, the SVM method can be used for prediction. The SVM method for solving regression problems is called Support Vector Regression (SVR) [10].

The SVR method in the hybrid control method is used for prediction (estimation) of the values of mean monthly water withdrawals from the reservoir $W_{T,\tau}$ in the future period $T = M+1$ and $\tau = N+1$. For learning the SVR model, mean monthly water flows into the reservoir $I_{T,\tau}$ are used, for $T = 1,2,...,M$, $\tau = 1,2,..., N$ and corresponding optimum values of mean monthly water outflows from the reservoir $W_{T,\tau}$ for each year $T = 1,2,...,M$ of the quasi-future period $\tau = N+1$. The learned SVR model estimates the amount of the monthly water withdrawal from the reservoir $W_{T=M+1,\tau=N+1}$. The outflow is estimated based on the mean monthly water flows into the reservoir $I_{T,\tau}$ which in terms of time, take place in the near past from the future time period, for which the SVR model estimates the withdrawal amount ($T = M+1$, $\tau = 1,2,..., N$). The algorithm of the SVR model is shown in Fig. 2.
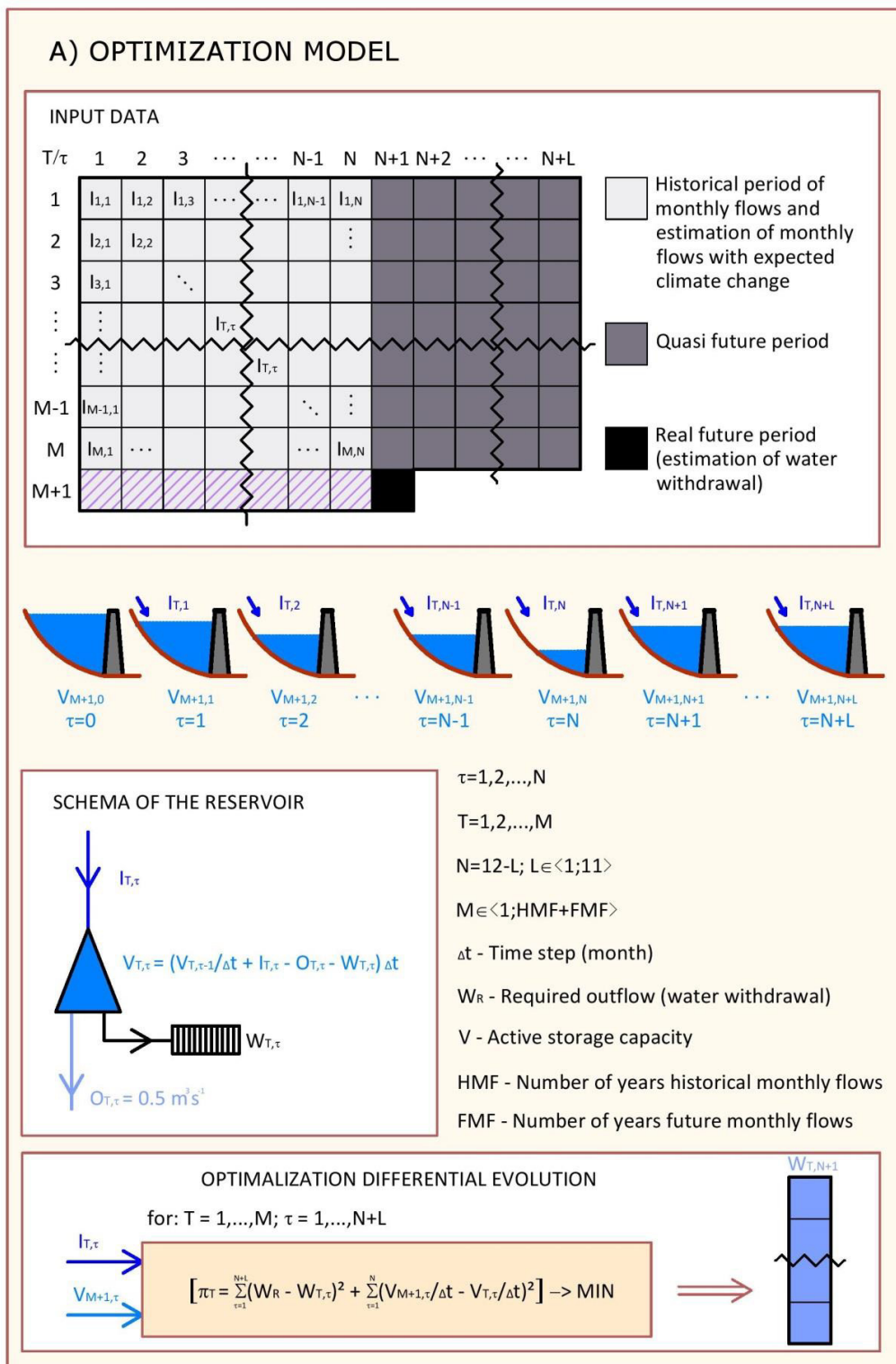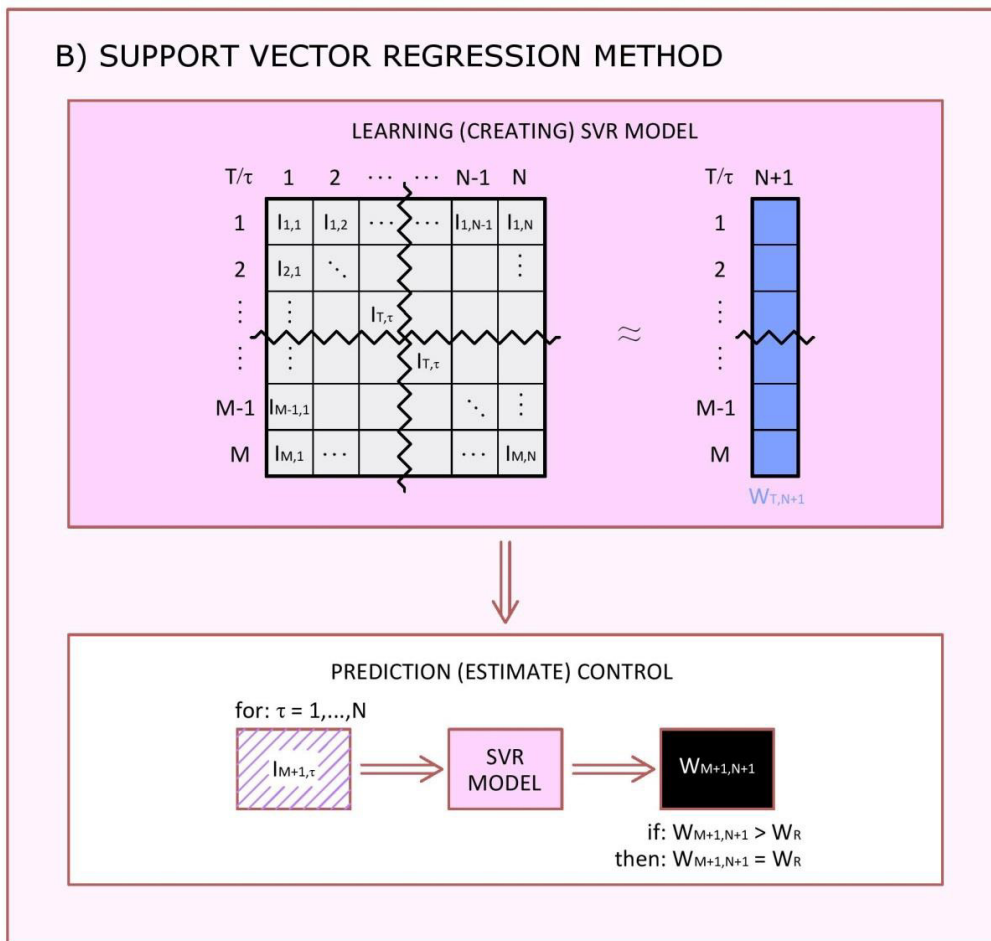
Fig. 1. Optimization model.

Fig. 2. Support vector regression method.

3. Application and Results

A program has been developed based on the described hybrid control algorithm. The program is created in the programming language R using the extension package DEoptim (Differential Evolution) and e1071 (SVR). The considered hybrid method of reservoir control has been applied in the storage function control of the Vir I reservoir (further referred to as Vir). The Vir reservoir is located in the Czech Republic and has a storage volume of 44.056 million m^3. Verification of the hybrid control method during real operation on the Vir reservoir would be practically impossible; therefore, a simulation model has been used for verification. It is a classical simulation model where control guidelines are substituted with the repeated algorithm of the hybrid control method. Simulation of the Vir reservoir control was conducted in the historical period of 1987 to 1995. The period of the years 1990 and 1992 was chosen for evaluation of the successfulness of control extreme dry years. In terms of extreme dry year, the year 1987 was above average, and so it is possible to consider at the beginning of simulation a full active storage volume for the reservoir.

Entry data for the hybrid control method:

- historical discharge series of mean monthly water flows into the reservoir; period from 1950 to 1987) – $HMF = 37$,
- estimated discharge series of mean monthly inflows into the reservoir for the chosen climate change scenario (ENSEMBLES [11]); period from 2000 to 2100 – $HMF = 101$,
- value of the required water withdrawal $W_R = 2.0 \ m^3.s^{-1}$,
- $M = 138$,
- $L = 6$,
- $N = 6$.

For the purpose of comparing the successfulness of hybrid control (HC), the control is compared with the month to month control. The month to month control corresponds with the control guidelines that are currently used for operation on the Vir reservoir (RC). This control method does not use water flow predictions either, and corresponds with common control methods.

For evaluation of the successfulness of individual reservoir control methods in the period from 1990 to 1992, the amount of unsupplied water is established. Ideally, 89.6 million m³ water should be supplied while maintaining the required W_R for a period of 17 months. Under RC control, only 64.1 million m³ water are supplied for the whole period. Under hybrid control, 66.5 million m³ water are supplied for the whole period.

Fig. 3 shows the course of mean monthly water flows into the reservoir (I). The required water withdrawal from the reservoir is shown (W_R). Furthermore, the figure shows the course of month to month RC control, and the course of HC control. Fig. 4 shows the courses of storage volumes for individual control variants, similarly as Fig. 3.
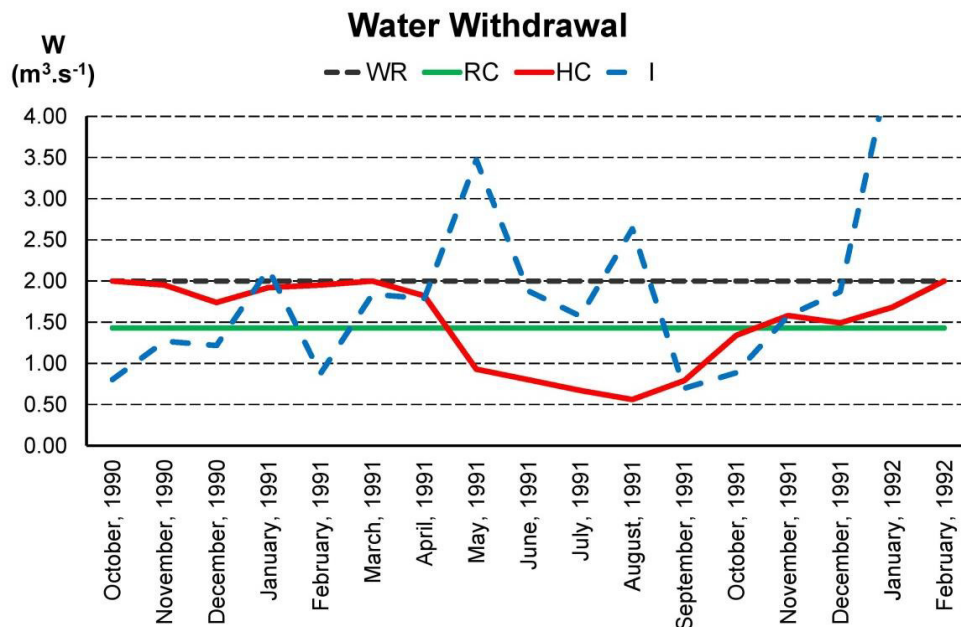

Fig. 3. The resulting courses of the control in the extreme dry period – mean monthly water flows.
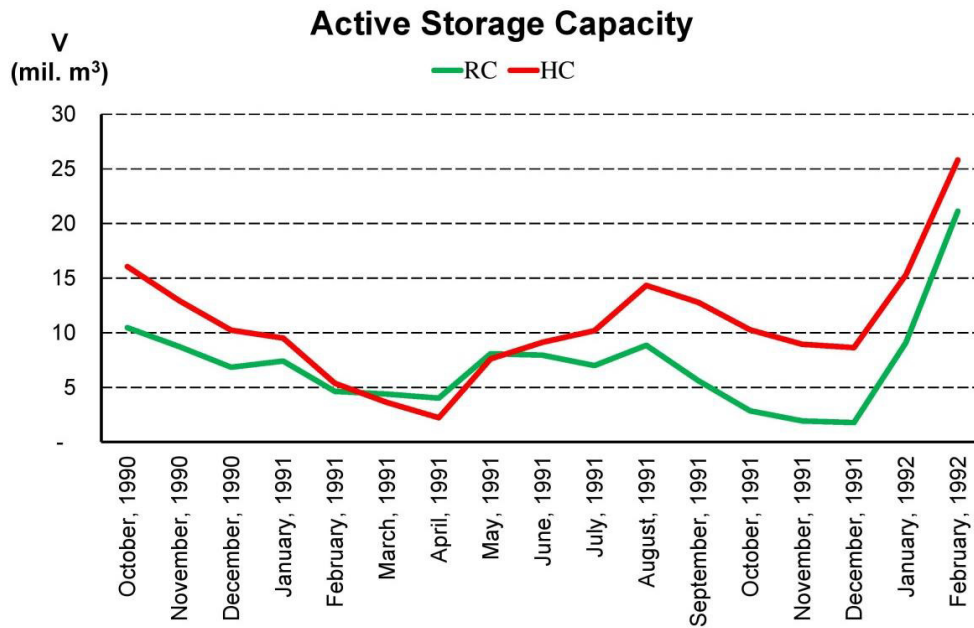
Active Storage Capacity

V (mil. m³)

Fig. 4. The resulting courses of the control in the extreme dry period – mean monthly storage volumes.

4. Conclusion

The aim of the paper was to outline an alternative method of strategic control of water withdrawal from a water reservoir. Strategic control of water withdrawal from reservoirs (control period within the time step of a month) is very important in the context of occurrence of a drought; it allows conducting appropriate manipulations on water reservoirs.

It is obvious from the case study that the total amount of unsupplied water is larger in the case of control using rules curves compared to the hybrid control method. It may be anticipated that with a different reservoir we will also obtain very interesting results using the hybrid control method. In terms of water management on the reservoir, it may be observed that hybrid control tends to withhold a larger amount of water in the reservoir, saving water for a future period.

In the future, it is advisable to try hybrid control with a different choice of *L (N)*, combined with a choice of a different climate scenario for the estimated discharge series of mean monthly inflows. The hybrid control method should also be used in the control of a different water reservoir, or the control be applied on a system of reservoirs. It is expected that even more interesting results might be obtained this way. In the future, the obtained results could be compared with the control using predictions of mean monthly inflows.

The results obtained in this paper point out the possibility of a practical use of the hybrid control method. The presented control method could serve as a means to make water management on reservoirs more efficient. In general, intelligent control methods may be a support providing tool for the water management control department in the process of decision making.

Acknowledgements

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