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Anticipatory real-time management in the Lake IJssel: implementation and practical application

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Abstract

In the Netherlands, flood protection has always been a key issue to protect settlements against storm surges and riverine floods. In addition, with the expected effects of climate change being more extreme, there is a need to address not only floods, but also droughts. In doing this, it is essential to adopt integrated and anticipatory techniques which are able to manage both.

In our research we present the application of such an anticipatory real-time control technique for the daily management of three connected lakes, together forming a large fresh-water reservoir in the hearth of the Netherlands. The main controlled water bodies are the Lake IJssel, which is the largest lake in Western Europe, and the neighboring Lake Marker and the Lakes Veluw. The area has a vital function both in preventing floods en droughts in the Netherlands: the lakes receive water from the River IJssel and from the neighboring water systems, managed by local Regional Water Authorities (Waterboards). Lake IJssel discharges during low tide in the downstream Wadden Sea. An anticipatory approach is very beneficial for this water system in order to release water in anticipation of high inflows or reduced discharge potential due to high sea levels. During droughts, real-time control techniques support the optimal distribution of limited available fresh water.

In collaboration with the National Water Authority (Rijkswaterstaat), an advisory module based on Model Predictive Control has now been implemented in the Operational Management System for Regulated Water Bodies for the Netherlands (RWsOS-IWP) and produces a daily operational advice for the management of the structures regulating the lakes. We explain how we set-up the prediction model (RTC-Tools) into the Operational System (Delft-FEWS), which real time forcing are used and how the different optimization goals are implemented. Special attention is paid to the presentation of the complex output of the advisory modules to the operators.

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1. Introduction

1.1. Managing lowland freshwater reservoirs in a changing climate

In the Netherlands, like in many other countries in the world, lowland freshwater reservoirs fulfill multiple important functions. They do not only provide drinking water for surrounding communities, they also are an important source of fresh water for irrigation systems and often they have recreational, navigational and natural conservation purposes. In the case of the Netherlands they also provide a buffer for draining the neighboring lands in wet periods.

In general, most infrastructure and land use has been designed to deal with the meteorological variability of the past hundred years. The focus thereby has mainly been on structural measures. It is expected though that the effects of climate change will increase the strain on the fresh water reservoirs and current-day infrastructure will not be sufficient when operated in a traditional way.

Fortunately, the present-day meteorological and hydrological forecasts and real-time monitoring systems [1] enable the application of more advanced real-time control techniques for operating the existing hydraulic infrastructure in an anticipatory and more efficient way [2], therefore delaying the implementation of new infrastructure. One of the most promising techniques is Model Predictive Control (MPC). It combines the prediction of future system states by an internal model with optimization algorithms for finding optimal control trajectories for actuators such as hydraulic structures. MPC originates from the industrial field in 1970's and already has a large application in irrigation canals and rivers [3] [4] [5]. The technique has been applied to multi-reservoir systems [6] and Dutch polders [7].

The National Water Authority (Rijkswaterstaat) operates the Operational Monitoring System for regulated water systems (RWsOS-IWP) for the management of all the water bodies under her authority. We developed an advisory module for the operation of the three connected lakes, together forming a large fresh-water reservoir in the hearth of the Netherlands. The module does not control structures directly. RWsOS-IWP is implemented in Delft-FEWS [8], a platform for managing real-time data acquisition, running of different hydrological and control modules as well as data visualization and presentation. The advisory module is based on advanced nonlinear MPC, implemented in RTC-Tools [9], an open source framework for traditional feedback control and MPC. RTC-Tools contains both hydrological and multiple hydraulic models to simulate and control water systems. It has been increasingly applied for control of hydropower dams and riverine systems [6]. The main objective of the advisory module is to keep the water levels of the lakes at set point. As discussed later in this work, usability of the advices and communication with the operators are essential objectives of the presented work, in order to guarantee its implementation in the daily operation.

1.2. Sequential nonlinear Model Predictive Control

Model Predictive Control (MPC) considers a discrete time dynamical system according to

$$x_k = f(x_{k-1}, u_k, d_k) \tag{1}$$

where x, u, d are respectively the state, control and disturbance vectors, and f( ) is a function representing an arbitrary water resources model. In Model Predictive Control Eq. (1) is used for predicting future trajectories of the state vector x over a finite time horizon k = 1,…,N in order to determine the optimal set of controlled variables u by an optimization algorithm. Under the hypothesis of knowing the realization of the disturbance d over the time horizon, i.e. the trajectory $\{d_k\}_1^N$, a Sequential Nonlinear MPC problem can be formulated as follows:

$$\min_u \sum_{k=1}^{N} J(\tilde{x}_k(u,d), u_k) + E(\tilde{x}_N(u,d), u_N) \tag{2}$$