IRRIGATION CANAL MODELS FOR AUTOMATIC CONTROL PURPOSES

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Abstract: *Automatic control is one way to improve irrigation canal management and to save water volumes during normal canal operation. In order to develop control algorithms for irrigation canals there is a need for simple linear models to be used in the algorithms. The following simple linear models are approximating the canal in order to give a base to develop control algorithms. The PAC-UPC laboratory canal (Prueba de Algoritmos de Control - Universitat Politècnica de Catalunya) is modelled (input and output discharge) using the following three models: Muskingum, Hayami and Integrator Delay Zero (IDZ) and the results are compared to measurements. All three models are able to describe the irrigation canal in an acceptable way. However, only the IDZ model can capture all the important characteristics. These tested models can be applied to represent real canals for control purposes where it is especially important to obtain good models without extensive measurements. Test campaigns are developped now in cooperation with the CHE (Confederación Hidrográfica del Ebro) in order to test control algorithms to be used in irrigation canals under their management.*

1. INTRODUCTION

Irrigation is the main user of fresh water all over the world. In some countries, 60 to 80% of total water resources are dedicated to irrigation. Automatic control of irrigation canals can be one way to improve water management in such a way that savings up to one third of water volumes can be achieved. In the heart of this process we find control algorithms who are in charge to decide how to move canal gates to meet irrigation needs in time and space.

In order to develop automatic control for irrigation canals (e.g. PID, predictive) there is a need for a simple linear model of the canal. These models can be developed in two different ways: experimentally (model identification) or analytically. In the first case, there is a need for measured data from the canal that is not always available. In the second case the analytical models are based on the geometrical parameters of the canals or in some cases they need few measured values but basically they need no previous tuning. Their advantage is hence that they can be applied to canals where there is no measured data available. There are three simple linear modes presented.

The models are tested on the UPC-PAC experimental canal. The models were developed for the UPC-PAC laboratory irrigation canal. The canal was specially designed to develop basic and applied research in the irrigation canals control area, it has a serpentine shape. The geometrical data of the canal is the following: it has a length of 220 m, width of 0.44 m and depth of 1 m. The canal has three gates, hence three pools and three offtake possibilities. Upstream of the canal there is a reservoir, and at downstream end there is a weir. The canal has zero slope. The canal disposes 11 level measuring sensors and 3 motorized gates whose information arrives to the SCADA system that can be used to implement different control algorithms. This canal can be used to test and develop control algorithms. We are having join activities with the Confederación Hidrográfica del Ebro, and some controllers are tested in the UPC-PAC canal that can be applied in the future in practice.

2. THE MODELS

a. The Muskingum model

The Muskingum model is a frequently used linear model for flood routing. It contains two equations, a continuity equation and a storage equation. The parameters of these equations are K and χ containing all the information about the river reach. The advantage of the model is the simplicity and linearity, however, the same characteristics are responsible for the disadvantages. It is a rough approximation of the non-linear behaviour of the canal. K is the storage time constant (with the dimension of time) for a river reach that can be well approximated by the travel time: this is the time it takes for one wave to travel through the reach. χ is a dimensionless coefficient weighing the relative effects of inflow and outflow on the reach storage. χ usually varies between 0-0.5 for reservoirs and 0-0.3 for stream channels.

a. The Hayami model

The Hayami model is derived from the diffusive wave equation, a simplified form of the Saint-Venant equations. It can be identified with first or second order Linear Time Invariant systems with the help of the momentum matching method. According to the properties of the canal different numbers of momenta are calculated and the resulting model can be first order, first order with delay or second order and in case of very long canals second order with delay.

a. The integrator delay model

This model assumes that the canal pool has two parts: a normal depth section and a backwater section. The backwater portion acts as reservoir with no time delay and no variation in water surface elevation. The other part is described by the delay time. The model is developed by combining these two parts.

3. METHODOLOGY DEVELOPPED

Due to zero slope, in cases the normal depth was needed a reference depth was used, that was measured in the canal in the upstream end in steady state with the reference discharge (70 l/s).

a. Muskingum model development

The following is the transfer function in the continuous Laplace domain:

$$G_m = \frac{1 - cs}{ds + 1}$$

Using the mentioned reference water depth and the chosen reference discharge, the Muskingum parameters can be calculated. The parameters χ and K were calculated in a way suggested by Cunge[3]. In this case the calculated parameters: c=42.38 d=44.93.

b. The Hayami model development

Using the formula suggested by Litrico[1] a first order model can be adjusted to the laboratory canal hence only the first momentum is matched. The value of the parameter is calculated using the formula given by Litrico[1] using the reference water depth, the reference discharge and the geometrical data of the canal.

The following is the transfer function in the continuous Laplace domain:

$$G_h = \frac{1}{bs+1}$$

In this case the calculated parameters: b=547.8.

c The integrator delay model

The parameters are calculated for the uniform flow and the backwater part. In case of the uniform part low and high frequency approximations are taken into account.[2] The canal partition is experimentally set to the middle since the zero slope the formula in the mentioned paper could not be used. The normal depth was approximated with the reference depth. The downstream depth was calculated using the weir equation. This model gives a complete transfer matrix between the water levels and the discharges. Since in this case discharge input- discharge output models are tested the model is combined with the linearized equation of the downstream weir. The transfer function is the following:

$$G_{id}(s) = \frac{(k+ls)e^{ms}}{ns+k}$$

In this case the calculated parameters: k = 0.01111, l = 1.220, m = -79.23, n = 3.465.

4. RESULTS

A discharge step was simulated by Simulink. The first step is from a smaller discharge to a reference discharge while the next step is from the reference discharge to a higher discharge. The responses of the different models are plot and compared with the measured output.

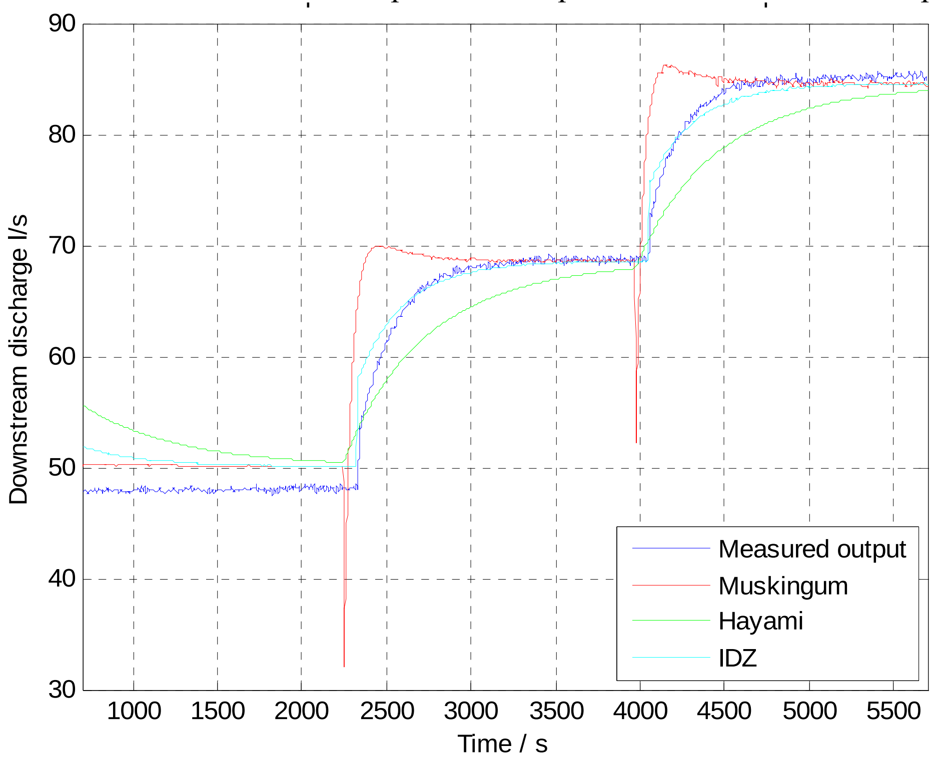

Figure 1 The measured and simulated response for an upstream step discharge

All models were tested without any tuning. The results are plot on Figure 1. All the three models followed the behaviour of the measured output. The Hayami model is slower than the measured output but arrives to the final state. The Muskigum model is slightly faster and also disposes a considerable undershoot before the step. The IDZ model approximated very well the canal behaviour. The delay time and the behaviour of the curve as well as the final state is very well approximated. This fact can be explained by the complexity of the IDZ model, while the poorer behaviour of the other two models can be explained by the few identified parameters. As a summary, all the three models showed the basic ability to give a simple model for an irrigation canal without measurements.

5. SUMMARY

The canal PAC-UPC is an experimental platform that can be used for testing existing control algorithms before applying them for real canals as well as to develop new algorithms. The canal includes all the most important characteristics of the real canals (like time delay) whereas it is available for tests all the time with the desired flow conditions. Supported by the numerical simulator, a wide range of tests can be carried out by testing before the algorithms numerically. Thanks to the different configurations (from one pool to 3 pools) SISO and MIMO algorithms can also be applied.

It is not only used for academic research. Control algorithms for the Confederación Hidrográfica del Ebro that are going to be applied in real canals are tested. The canal PAC-UPC is an open facility that can be used for those involved in irrigation canal management.

6. RFERENCES

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