RECURSIVE SYSTEM IDENTIFICATION FOR REAL-TIME SEWER FLOW FORECASTING

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ABSTRACT: On-line sewer flow forecasting is simulated in this study using an autoregressive transfer function rainfall-runoff model and a recursive procedure for parameter estimation. Reliable off-line estimates of the model parameters are assumed to be unavailable. Three recursive estimation algorithms are used: the time-invariant and time-varying versions of the recursive least-squares algorithm, and the Kalman filter interpretation of this algorithm. The sensitivity of the forecasting accuracy to the model order and to the initial conditions of the algorithm is studied using sewer flow data from the Milwaukee Metropolitan Sewerage District. It is observed that increasing the number of model parameters does not automatically improve the on-line forecasting results, although it does improve the off-line results. Also, the asymptotic properties of the recursive estimates appear to be better for the low-order models. It is observed that using the off-line identification results as the initial conditions for the recursive procedure produces more accurate forecasts than the (unreliable) model identified off-line without parameter updating. Forecasting results achieved using the time-invariant recursive least-squares algorithm are compared with those obtained for the time-varying approaches.

INTRODUCTION

Many studies have shown that the minimization of the combined sewer overflows and the optimization of the performance of existing facilities may require the implementation of dynamic real-time control (RTC) of the sewerage system components [see, e.g., Schilling (1989); Novotny and Olem (1994)]. Among the key requirements for a successful application of RTC is the availability of reliable real-time forecasts of sewer flow at various points within the system.

O'Connell and Clark (1981) list the following minimum requirements for a successful real-time flow forecasting model: (1) The model should be "adaptive"; that is, the model parameters should be adjustable to reflect the recently observed state of the system as additional data become available; (2) parameter estimation of the model should be performed recursively in real time to provide immediate response to the time-varying characteristics of the system; and (3) the model should be computationally efficient.

The choice of a rainfall-runoff model for most real-time forecasting applications is typically made between two types of lumped models: (1) Linear, purely stochastic input-output models; and (2) lumped, conceptual (deterministic) models that include stochastic components.

Stochastic input-output models are generally considered when the cause-and-effect relationships of the system are either unknown or too complex, or when the data requirements are too large (Patry 1986); the system under consideration is described as a "black box." Both the advantages and the disadvantages of this approach to system description are well known [see, e.g., Kitanidis and Bras (1980); Klemeš (1986); Patry (1986)]. An example of this type of model is the stochastic transfer function model. Novotny and Zheng (1989) showed that the deterministic component of the transfer function model in a combined sewer system is identical to the well-known unit hydrograph model.

Incorporating conceptual features into a model makes sense if a priori information about the system structure and the main processes is available; the system is described as a "gray box." Using a priori information implies an ability to forecast under conditions that did not exist during the parameter calibration (i.e., an ability to extrapolate to new conditions). Purely black-box models do not have a similar ability; their verification using independent data sets only constitutes an interpolation within conditions already encountered in calibration.

However, the more complex conceptual rainfall-runoff models must be simplified if they are to become adaptive; for example, background equations must be linearized. This linearization is not a simple procedure because most of these models represent threshold-type behaviors of the modeled processes (Kitanidis and Bras 1980; Bras and Rodriguez-Iturbe 1985); Rajaram and Georgakakos 1989).

Because of the simplifications required for conceptual models, these models may lose some of the advantages they derived from the use of the a priori information. Linear black-box models can be specified explicitly in analytical form, and recursive estimation methods are readily available for updating their forecasts in real time. The black-box models usually produce good forecasts if the following conditions are met: (1) The lead times are short in comparison with the response time of the system; (2) the system changes are slow; (3) the errors in the input data are large and those in the output data are small; and (4) runoff is not significantly affected by the previous conditions (i.e., the runoff coefficient used with the well-known rational method is approximately constant from one rainfall to the next). The conditions listed are consistent with the most common situations in urban runoff and sewer flow forecasting. Therefore, only black-box transfer function models are considered below.

APPLICATIONS OF RECURSIVE PARAMETER ESTIMATION IN HYDROLOGICAL ENGINEERING: BRIEF OVERVIEW

Hino (1973) was among the first to report an application of a recursive estimation approach to the problem of real-time river runoff forecasting and presented examples of identifying the ordinates of a unit hydrograph using the Kalman filter techniques. The dynamics of the parameter vector were described as a random walk. Both parameters and measurement noise covariances were assumed constant. Parameter variation under different initial conditions and different inputs was studied.

Wood and Szöllösi-Nagy (1978) used a recursive procedure to estimate parameters under time-varying noise covariances.

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Note. Discussion open until December 1, 1999. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on March 17, 1997. This paper is part of the ***Journal of Hydrologic Engineering***, Vol. 4, No. 3, July, 1999. ©ASCE, ISSN 1084-0699/99/0003-0280–0287/$8.00 + $.50 per page. Paper No. 15358.