SWITCHING REGIME ANALYSIS FOR NONLINEAR HYDROLOGIC TIME SERIES

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Time series models are valuable analytical tools for assessing potential impacts of climate change on water resources systems. Change points were normally searched and examined before time series modeling was conducted (Brockwell and Davis, 1991). In addition to classical sequential analysis, many innovative methods such as Bayesian estimation and Markov Chain Monte-Carlo simulation were proposed to deal with change-detections in time series modeling. A common disadvantage with the Bayesian methods is their incapability of handling nonlinear models. Linear time series models and their corresponding change-point detection methods basically do not support insight into switching regimes in time series dynamics. Linear models for hydrologic forecasting and simulation have gained limited acceptance in real-world practices (Lall et al., 1994). Nonlinear time series analysis has been applied in many hydrologic studies (Porporato and Ridolfi, 1997; Sangoyomi et al., 1996; Zaldivar et al., 2000). However, it is relatively hard to analyze the system dynamics due to the nonlinear nature of the models.

As an extension of previous efforts, an approach was proposed to detect switching dynamics for hydrologic time series based on a hidden Markov model. A hypothetical case with the Mackey-Glass time series (Mackey and Glass, 1977) was used to demonstrate the applicability of the proposed hidden Markov model approach to change-regime analysis. The generated data and artificially switching-modes set are depicted in Fig. 2(a) and (b), respectively. Fig. 2(c) presents the detected segments with the proposed HMM method. As shown in Fig. 2(c), mode switches are located close to most of the points originally set in MacKay-Glass time series. Exceptions, however, can be observed at some detected change points. For example, three extra switches were identified by the algorithm, and they resulted in short mode segments than original ones. The in-depth examination of the data discovered that there experienced apparent changes at those locations according to the data characteristics ($t = 490$, $t = 1280$, and $t = 1500$); but delay parameters remained same around the points. The ideal resulted from this case of chaotic Mackay-Glass time series indicated that the proposed HMM method could be used to deal with change analysis for data series with nonlinear form. Some hydrologic time series such as daily river flow and climate data are featured by long term chaotic information of sequence parameters. The application of the HMM change detection method to selected hydrologic time series may offer in-depth insight into system dynamics.

As a comparison, a linearization approach was also applied to analyzing the same Mackay-Glass time series. Fig. 2(d) presents that only two change points are identified by the linearization/CUSUM approach. The both points were directly noticeable at $t = 1120$ and $t = 2060$, respectively. In Figure 2(d), the data series undergoes an abrupt level change at the first detected point as a result of the manipulation on the data. Also obviously, Figure 2(d) presents that the series has a slightly deceasing trend starting from the second detected point. However, none of other mode switches set in Mackay-Glass time series was recovered. This was consistent with the expectation because only linear trend could basically be found by change analysis for linear systems. Figure 2(d) illustrates the linear trends obtained over the data series.

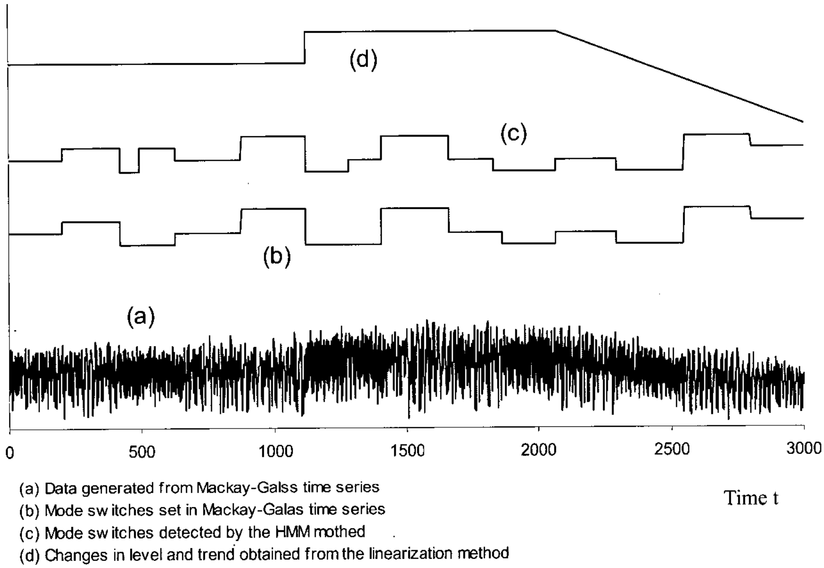

Fig. 2 Time series data and switching regime detection

Compared to the linearization/CUSUM approach which were primarily designed for change point identification in linear systems, the HMM algorithm was more useful and applicable for analyzing internal dynamics in long-term chaotic time series. Although linearization techniques were computationally efficient, they were not usually applicable to the problems where the nonlinear effects were significant. This research is aimed at the development of a general approach to switching regime analysis on dynamic systems through using the hidden Markov model. Future effort is to apply this method to a real case of analyzing the effect of climate change on hydrologic behavior in an urbanizing watershed.