Ocean Engineering 84 (2014) 145–156

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Adaptive neuro-fuzzy inference system for the prediction of monthly shoreline changes in northeastern Taiwan

Fi-John Chang*, Horng-Cherng Lai

Department of Bioenvironmental Systems Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Da-An District, Taipei 10617, Taiwan, ROC

ARTICLE INFO

Article history:
Received 6 September 2013
Accepted 15 March 2014
Available online 4 May 2014

Keywords:
Shoreline change
Shoreline erosion
Adaptive neuro-fuzzy inference system (ANFIS)

ABSTRACT

This study intends to model the shoreline change by investigating monthly shoreline position data collected from seven sandy beaches located at the Yilan County in Taiwan during 2004–2011. The harmonic analysis results indicate shorelines appear significantly periodic with great variation. The adaptive neuro-fuzzy inference system network (ANFIS) is configured with two scenarios, namely lumped and site-specific ones, to extract significant features of shoreline changes for making shoreline position predictions in the next year. The lumped models for all stations are first investigated based on a number of possible input information, such as month, location, and the maximum and mean wave heights. The results, however, are not as favorable as expected, and wave heights do not contribute to modeling due to their high variability. Consequently, a site-specific model is constructed for each station, with its current position and nearby stations' positions as model inputs, to predict its shoreline position in the next year. Compared with the harmonic analysis and the autoregressive exogenous (ARX) model, the ANFIS model produces more accurate prediction results. The results indicate that the constructed ANFIS models can accurately predict shoreline changes and can serve as a valuable tool for future coastline erosion warning and management.

1. Introduction

Shoreline erosion is a worldwide problem that causes a major concern to the socio-economic developments in coastal cities for many countries (Chen and Zong, 1998; Genz et al., 2007). Bird (1985) indicated that about 70% of the world's sandy beaches retreated at a rate of 0.5–1.0 m per year. The increasingly intensive human activities in river basins and/or along coasts enlarge coastal erosion areas and aggravate erosion processes, and thus cause land losses; moreover the global climate change in the past decades results in rising sea levels (IPCC, 2007; Church et al., 2008) and accelerates the sand losses of beaches (Bruun, 1962; Davidson-Arnott, 2005). Such threat is particularly severe in Taiwan, an island bearing intense shoreline changes. Recent surveys indicate that more than 80% of the island's sandy beaches have undergone erosion over the past three decades and coastal erosion has occurred along most of sandy shores at an alarming rate, which becomes an island-wide problem in Taiwan (Hsu et al., 2007). Therefore, the environmental protection against beach loss, disaster warning systems for coastal zones and appropriate land management along the coasts are critical issues that need to be carefully studied and adequately developed.

Shorelines are known to be unstable and vary over time. Short-term changes occur over decadal time scales, more or less, and are related to daily, monthly and seasonal variations in tides, currents, wave climate, episodic events and anthropogenic factors. Shoreline movement is a complex phenomenon and involves distinguishing long-term shoreline movement (signal) from short-term changes (noise). Analysis of shoreline variability and erosion–accretion trend is elementally important to coastal scientists, engineers and managers (Douglas and Crowell, 2000). Both coastal management and engineering design requires information of the past, current and future shoreline positions. Successful coastal management requires long-term shoreline erosion rates to be determined and forecasts made of future shoreline positions along with the estimates of their uncertainty (Douglas and Crowell, 2000). Shoreline erosion–accretion is driven by both natural and human factors in response to the complexity of coastal hydrodynamics. Natural factors involve sea levels, tidal waves, crust changes, typhoons, and sand particle size as well as sediment transport in nearby rivers while human factors involve land subsidence induced by groundwater overpumping, illegal sand and gravel mining in river basins, a series of dams on rivers for reducing sediment transport to costal

* Corresponding author. Tel.: +886 2 23639461; fax: +886 2 23635854.
E-mail address: changfj@ntu.edu.tw (F.-J. Chang).

http://dx.doi.org/10.1016/j.oceaneng.2014.03.020
0029-8018/

zones, and flow conditions varied by local terrains rendered from coastal structures, which could significantly alter coastal landforms (Hsu et al., 2007). Although great efforts have been devoted to quantifying the rates of shoreline movement and obtaining the empirical relationships between shoreline changes and the variables affecting the change process (Hsu, 1999), a definite solution, if impossible, is still far away and has not yet been found.

Shoreline change prediction has gained considerable attention; nevertheless, little consensus has been made on the best predictive methodology due to the complex heterogeneity of coastal geomorphology and sediment-transport processes. In general, the study of coastal hydrodynamic processes can be divided into: (1) numerical models; (2) physical (hydraulic) models; and (3) field measurement data analysis (Hughes, 1993). Numerical simulation methods are frequently used to simulate and predict the influence of coastal engineering works on coastal hydrodynamics. For instance, Zhong (2003) applied the two-dimensional SBEACH numerical analysis method to establishing a beach section variation model for predicting the beach section change effect under monsoon- and typhoon-induced waves. The Water Resources Agency, Taiwan (2008) adopted numerical methods to assess coastal changes around Taiwan and found that the sediment transportation in the Lanyang River played an important role in the shoreline shape along the Yilan Coast. However, due to the dynamics and complexity of costal environment, simulation results commonly bear great uncertainty and/or vagueness, and thus could not well represent actual phenomena. Moreover, with limited observational data related to a large number of parameters, model validation in general could not be fully conducted and measured. Hydraulic models are usually adopted in large-scale development projects for investigating the behavioral characteristics of erosion profiles. Because of scale effects, the profile changes in small-scale laboratory experiments, however, cannot be transferred directly to field situations. Besides, hydraulic models are not recommended for long-term prediction because data collection and model verification processes are laborious, time consuming and costly. Alternatively, empirical equations have been developed to predict beach profiles based on simple environmental parameters such as wave height, wave period, grain-size or sediment fall speed (Kriebel, 1987).

Field data analysis can be used to judge shoreline change rates as well as predict future shoreline changes. It has been recently considered as a more effective reflection of the shoreline change process and a more reliable estimation approach than numerical simulation and physical models (Dolan et al., 1991; Douglas et al., 1998). The shoreline position change of the US East Coast in the 19th century indicated that the linear regression model was appropriate in certain cases, namely shorelines were unaffected by inlets or engineering changes (Douglas and Crowell, 2000). The problem with linear regression models is that they work well only when the assumptions of underlying linearity and normal distribution are fulfilled. However, in some cases with poor quality data, linear regression assumptions may be violated. Uncertainties in the extracted shoreline data need to be appropriately addressed if those data are to be used to predict future shoreline positions for sustainable coastal management (Appeaning Addo et al., 2008). Honeycutt et al. (2001) proposed that long-term prediction of shoreline change could be more accurate without the use of storm data after investigating the prediction results of shoreline change rates with and without the use of storm data, respectively. Özolçer (2008) considered that there was a strong correlation between coastal topography changes and wave heights. Kerh et al. (2009) extracted beach locations from aerial photographs and configured artificial neural networks to predict long-term shoreline changes. These approaches were mainly developed for estimating long-term shoreline changes. Taiwan is located on the main track of western North Pacific typhoons. Rapid erosion and the recovery of beach width after ordinary storms is well known, consequently shoreline positions can have a highly irregular temporal pattern. A total of 187 typhoons invaded Taiwan during 1958 and 2012, i.e., 3.4 typhoons per year in average. Shoreline changes in Taiwan can be quick and dramatic, and thus easily bring disasters (Yan, 2005). Consequently developing accurate prediction models of coastal erosion is vitally important and critical to coastal managers for protecting resident safety, public investments and private properties in the coastal zones.

Artificial neural networks (ANNs) mimic human nervous system to effectively learn and wisely provide human-like activities. They can efficiently handle large amounts of high dimensional data and process messages with excellent nonlinear mapping ability and fault tolerance property. ANNs have been extensively used in hydrological forecasting with great satisfaction for decades (Maier and Dandy, 2000; Dawson and Wilby, 2001; Chang and Chen, 2003; Wang et al., 2009; Tiwari and Chatterjee, 2010; Abrahart et al., 2012). Various types of neural networks have been developed, such as multi-layer feedforward neural network, recurrent neural networks, and the adaptive network fuzzy inference system (ANFIS) (Haykin, 1999; Ham and Kostanic, 2000). We notice that choosing a suitable neural network for a given problem is however still more of an art than a science. The ANFIS, proposed by Jang (1993), fuses the fuzzy inference system into the neural network to simultaneously possess the self-learning and self-organizing capabilities. It increases the learning and memory capacity that the fuzzy theory lacks for and provides the flexibility to deal with uncertainty and imprecision (Sauty, 1980; Çelikyilmaz and Türksen, 2009). The ANFIS succeeds in various applications of different fields, such as motor fault detection systems (Ertunc et al., 2012), dynamic power load systems (Singh and Chandra, 2011), reservoir operating systems (Chang et al., 2005; Chang and Chang, 2006), and sea level forecasts (Huang et al., 2003; Sztobryn, 2003; Makarynskyy, 2004; Makarynskyy et al., 2004; Lin and Chang, 2008; Ghorbani et al., 2010). Talebizadeh and Moridnejad (2011) discussed further about the estimation of the uncertainty caused by the error in measuring variables, the uncertainty in the outputs of ANN and ANFIS models, and initial configurations prior to training.

The complex coastal change process mainly links between hydrodynamic forcing and the morphological response of the beach to sediment transport through waves (Cowell et al., 1999; Omhoog Masselink and Huges, 2003). Many modeling efforts, particularly conceptual and/or physical models based on available pre-knowledge, have provided further evidences and/or gained more solid interactive mechanisms, which greatly enhance the understanding of the underlying study process. Nevertheless, there is still no clear consensus on the subject, partly because related parameters (bedload, waves, sediment, etc.) are very difficult to measure under field conditions. Despite considerable researches on describing the past shoreline changes and/or predicting future ones (Cowell et al., 1995; Boak and Turner, 2005; Quartel et al., 2008; Davidson and Turner, 2009; Davidson et al., 2010; Alegria-Arzaburu et al., 2010; Del Río et al., 2013; Long and Plant, 2012; Osorio et al., 2012; Liu et al., 2013), to our best knowledge, only a few studies attempted to use ANNs for predicting shoreline variations (Muslim et al., 2006; Alizadeh et al., 2011; Goncalves et al., 2012). Therefore a consensus has emerged on the use of ANNs for forecasting future shoreline positions. Based on the best of our knowledge and previous research references regarding the coastal change modeling and available measurements in the study area, this study discusses the possibility of developing a short-term prediction model using different sources of temporal geodetic data with three different shoreline prediction