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An EMD-recursive ARIMA method to predict wind speed for railway strong wind warning system

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A B S T R A C T

To protect running trains against the strong crosswind along Chinese Qinghai–Tibet railway, a strong wind warning system is developed. As one of the most important technologies of the developed system, a new short-term wind speed forecasting method is proposed by adopting the Empirical Mode Decomposition (EMD) and the improved Recursive Autoregressive Integrated Moving Average (RARIMA) model. The proposed forecasting method consists of three computational steps as: (a) use the EMD method to decompose the original wind speed data into a group of wind speed sub-layers; (b) build the forecasting models for all the decomposed sub-layers by utilizing the RARIMA algorithm; (c) employ the built RARIMA models to predict the wind speed in the sub-layers; and (d) summarize the predicted results of the wind speed sub-layers to get the final forecasting results for the original wind speed. Since the wind speed forecasting method is proposed for the real-time warning system, the forecasting accuracy and the time performance of the forecasting computation are both considered. Two experiments show that: (a) the proposed method has better forecasting performance than the traditional Autoregressive Integrated Moving Average (ARIMA) model, the Persistent Random Walk Model (PRWM) and the Back Propagation (BP) neural networks; and (b) the proposed method has satisfactory performance in both of the accuracy and the time performance.

1. Introduction

In recent decade, there are several derailment accidents happened in the world caused by strong crosswind. A train consisting of six vehicles was derailed between Akita station and Niigata station in Uetsu railway line on December 25, 2005 in Japan (Train death toll rises in Japan, 2005). The investigators from the Department of Traffic Safety of East Japan Railway Company confirmed that the train derailment was caused by the strong wind along the Uetsu line. Eleven vehicles of a train were blown over in Xinjiang railway on February 28, 2007 in China (Chen et al., 2010; Strong wind topples Chinese train, 2007). The reason of the derailment proposed by the Ministry of Railway of China was also the strong crosswind. Unfortunately, similar train derailment accidents also happened in Canada (Freight train derails in southern Saskatchewan, 2014) and USA (Shust et al., 2010).

Aimed at the issue of the train derailment under the strong crosswind, some important results have been studied and published. A numerical-experimental procedure was provided for the aerodynamic optimization of a new train named EMUV250 in terms of behaviors to the crosswind (Cheli et al., 2010). In the numerical experiment, two different train shapes were proposed by modifying the train's roof and nose. A new framework was proposed for the consideration of the effects of crosswind on trains based on correcting the current CEN methodology (Baker, 2013). In the framework, an improved methodology was presented, which can be used for the train authorization and the route risk analysis. A numerical calculation was conducted to investigate the safe domain of a train in crosswind caused by different attitudes (Cui et al., 2014). A methodology was put forward for the safety assessment to the risk of a train overturning in strong cross-wind (Andersson et al., 2004). The proposed methodology had been applied in a high-speed railway named Botniabanan line with a maximum speed of 250 km/h in the northeast coastal region of Sweden.

Besides the upper important studies, some scientist presented that developing railway strong wind warning systems is also a feasible option to protect the running trains (Hoppmann et al., 2002; Kobayashi and Shimamura, 2003; Liu et al., 2009; Pan et al., 2008). In these warning systems, the short-term wind speed prediction is one of

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the most important technologies. However, since the wind speed signal is non-stationary and stochastic, it is difficult to predict it accurately. To study the internal characters of stochastic wind speed signals, a simulation algorithm was proposed to generate sample functions of a stationary, multivariate stochastic process according to its prescribed cross-spectral density matrix (Deodatis, 1996). Currently, the wind speed forecasting methods for railway applications can be classified as three types: physical methods, statistical methods and intelligent methods. The physical models adopt the physical parameters (e.g., terrains, obstacles, pressures and temperatures, etc) to estimate the future three-dimensional railway wind speed. Due to the time performance of the physical methods, they are suitable for the off-line estimation but not the real-time decision in the warning systems. A representatively physical method was proposed by the University of Genoa to study the wind hazard of the Rome–Naples High Speed (HS)/High Capacity (HC) railway line. In this physical methods, the wind numerical simulation and the probabilistic assessment of the simulated wind speed results along the line were completed (Burlando et al., 2010; Freda and Solari, 2010). The second type is the statistical methods, which utilize the statistical models to describe the changing law of the wind speed for the future prediction. A wind speed statistical forecasting model was proposed for the 'Nowcasting' warning system developed by Deutsche Bahn AG in Germany (Hoppmann et al., 2002). In this method a linear extrapolated algorithm was used to get the future wind speed prediction by combining the average values of the historical wind speed data, the estimated gust supplement and the error supplement. Although the statistical methods are always simple and good at the real-time performance, their accuracy can be further improved. The intelligent methods focusing on the intelligent forecasting models. A wind speed intelligent predicting method was presented using Kalman Filter theory for the 'Windas' system from Japanese East Railway Company (Kobayashi and Shimamura, 2003). Although the intelligent methods can have better accuracy than the physical and statistical ones, sometimes they have the problems in the computational convergence. From the upper references (Hoppmann et al., 2002; Kobayashi and Shimamura, 2003), it can also be found that currently in the strong wind warning systems only the wind speed signals but not the wind direction signals are processed and used to present the warning commands. The reasons of this condition can be explained as follows: (a) compared to the wind speed prediction, the wind direction prediction is more difficult. Because the wind direction signals are always more non-stationary than the wind speed signals; (b) although the wind direction data at a position can be measured conveniently, the real angles between the running trains and the real-time wind direction signals cannot be calculated accurately. Because the train real-time postures are dynamic and nonlinear; and (c) it is not difficult for these warning systems to measure both the wind speed data and the wind direction data at a large number of wind stations at the same time, but it can be a challenge for these systems to calculate the wind speed predictions then to propose the critical safety velocities under huge different combinations of wind speed and wind direction synchronously.

In this study, we focus on the wind speed high-accuracy predictions for the railway wind warning systems. By considering both the forecasting accuracy and the real-time performance, the statistical methods have been selected in this study. A new hybrid statistical wind speed forecasting method is proposed by combing the Empirical Mode Decomposition (EMD) and the improved recursive ARIMA (RARIMA) model. In the proposed hybrid method, not only a new RARIMA model is presented to calculate the wind speed predictions, but also it is the first time to adopt the EMD algorithm to process and decompose the original non-stationary wind speed data. Additionally, a comparison of the forecasting performance made by different models is provided. The comparing models include the proposed EMD-RARIMA model, the standard Autoregressive Integrated Moving Average (ARIMA) model, the Back Propagation (BP) neural network and the Persistent Random Walk Model (PRWM). The paper is organized as follows: Section 2 presents the architecture of the strong wind warning system; Section 3 explains the detailed steps of the wind speed prediction; Section 4 provides the experimental results of two cases; and Section 5 concludes this study.

2. Strong wind warning system for Qinghai–Tibet railway

2.1. System architecture

The Chinese Qinghai–Tibet railway is the highest railway line in the world, which covers a big plateau area from the Geermu city in

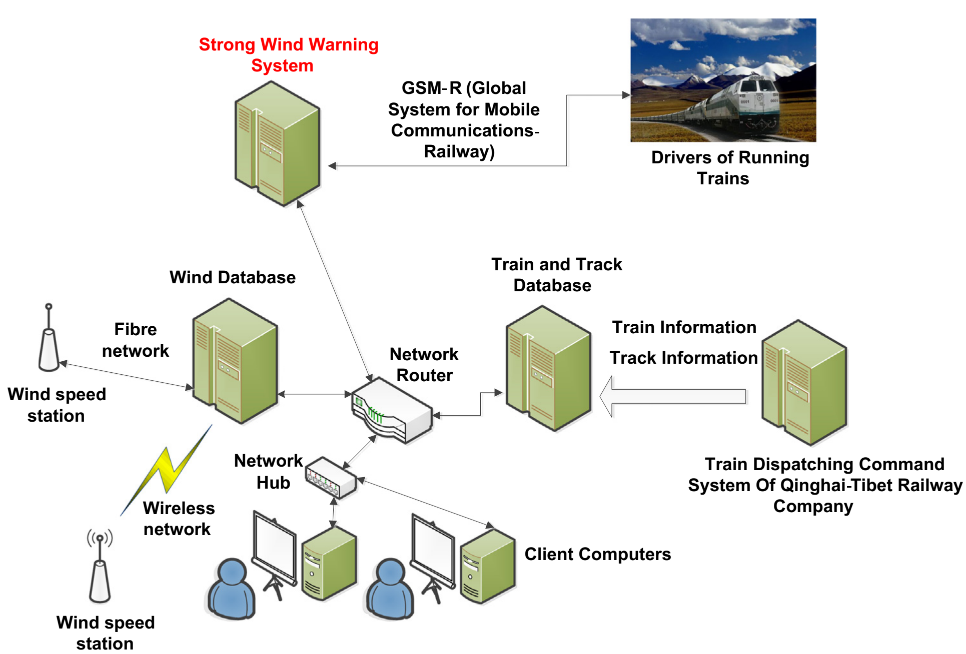

Fig. 1. Architecture of the strong wind warning system for the Qinghai–Tibet railway.