Data Prediction Model Based on LSTM Neural Network in Bridge Health Monitoring System

Shihui Xiao¹, Shengfang Qiao²-⁵*, Hang Chen², Xi Liu², Yue Li², Mengxiong Tang²-⁴, Hesong Hu², Gaotang Li³

¹Zhuhai Da Hengqin Co. Ltd, Zhuhai 519000, China
²Guangzhou Institute of Building Science, Guangzhou 510440, China
³China Railway 20th Bureau Group Co. Ltd, XiAn 710000, China
⁴Guangzhou Construction Engineering Co., Ltd, Guangzhou 510000, China
⁵South China University of Technology, Guangzhou 510641, China

Email: 1050577552@qq.com

Abstract. The abnormal value was common in bridge health monitoring system. The prediction model based on LSTM neural network in bridge health monitoring system was studied in this paper. The modeling process was discussed about LSTM neural network model. The LSTM neural network model was also used to analysis the actual data in bridge. The results indicated that the prediction accuracy of LSTM model was high. Thus, the LSTM neural network could be used to analyze and predict data in bridge monitoring system.

1. Introduction

The occurrence of bridge safety accidents was hard to be be avoided just by design and construction checking calculation in a large number of painful lessons, and the monitoring operation as the last barrier for engineering safety played an important role in the early warning of safety accidents. However, the continuity and real-time performance of the traditional manual monitoring method was poor, so it was not easy to find the hidden danger in time, and it was difficult to guarantee the safety fundamentally. Therefore, it was of great significance to introduce the Internet of things, intelligent sensing equipment and other advanced technical means. Thus, the bridge health monitoring system was highlighted.

However, data processing was crucial to bridge health monitoring system, which was the premise of structural safety warning, damage identification and comprehensive bridge health assessment. With the rise and application of intelligent algorithm, the research of bridge structure health monitoring was effectively promoted. Intelligent algorithms represented by neural networks have been widely applied, which could simulate arbitrary nonlinear systems [1] and have a good convergence effect. The data-driven structural damage identification method was proposed based on neural network algorithm, which could effectively analyze structural response in Weinstein et al. [2]. The monitoring data prediction method with multiple associated parameters was established by using BP neural network in Zhou et al. [3-6], and found that BP neural network has a high prediction accuracy and meets the requirements of engineering application. BP neural network and recurrent neural network have achieved good application effect in monitoring data processing previously. However, the computational efficiency of BP neural network decreases significantly when the monitoring data volume augments. Moreover, there are some problems such as gradient explosion or vanishing. In order to solve the problems in BP and other neural network algorithms, LSTM neural network has...
been presented. The problems such as gradient explosion or disappearance could be effectively solved in LSTM neural network, which could provide new ideas for mass monitoring data processing.

The data prediction model was put forward in this paper, which based on LSTM neural network in bridge health monitoring system. The implementation process and application effect of LSTM neural network was discussed in bridge health monitoring data of practical engineering.

2. Introduction to Data Prediction Model Based on LSTM Neural Network

2.1. LSTM Neural Network
LSTM was found to process large amounts of short-term time series data quickly and accurately, which was suitable for nonlinear regression variables with a high model accuracy and fast training speed. LSTM unit structure was shown in figure 1. There were three control doors, including Input Gate, the Output Gate and Forget Gate. The output of three doors was connected to a multiplication unit respectively, which could control network's Input Gate, Output Gate, and the state of the Cell unit.

![LSTM Neural Network](image)

Figure 1. LSTM Neural Network.

2.2. Data Prediction Model
The data prediction model was established based on LSTM neural network, which used Python language and TensorFlow. The main structure of LSTM neural network consists of three LSTM neural layers and two full connection layers. Each LSTM neural layer contains 200 nodes. Moreover, the BN layer was added in front of each LSTM neural layer, followed by Dropout layer, and the inactivation probability was set as 0.2 in Ioffe and Szegedy [7]. The calculation structure of LSTM neural network was shown in figure 2.
2.3. Evaluation Model
Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) were used as evaluation criteria for the prediction accuracy of the algorithm. Both RMSE and MAE represent the Error between the predicted value and the true value. The lower the RMSE and MAE is, the smaller the algorithm error will be. The RMSE and MAE could be derived as follows.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{n}} \quad \text{MAE} = \frac{\sum_{i=1}^{n} |y_i - \hat{y}_i|}{n}$$

$n$ was the total number of predicted results, $y_i$ and $\hat{y}_i$ were the true value and predicted value respectively.

3. Case Study

3.1. Data Sample
The data sample was the monitoring data of vibrating string strain gauge from the bridge monitoring system in Zhuhai, China. The time period is 18 April 2019 to 14 May 2019, as shown in figure 3, which was the time-domain curve of the monitoring data. There were 2690 sets of vibrating string frequency monitoring data, which were used for model training, prediction and verification.

3.2. Model Validation
The 2690 sets of data were divided into two groups, namely the training data set (accounting for 90%) and the test data set (accounting for 10%) in figure 3. The LSTM model was constructed with TensorFlow deep learning framework and trained with training set data. The trained LSTM model was used for regression prediction analysis of the last 550 sets of data in figure 3. The fitting result of test data was shown in figure 4, and the prediction error was presented in figure 5.
4. Results and Discussion

In Figure 4 and Figure 5, the prediction data of LSTM models has a small error with the actual data. The RMSE and MAE of prediction results were 0.32Hz and 0.12Hz respectively. Further, it could be obtained that the prediction error of LSTM model was -0.56%~0.60%, which indicated that the predicted value was basically the same as the actual value and could meet the requirements of engineering accuracy. At the same time, the prediction effect of LSTM neural network was stable in different periods.

5. Conclusion

The prediction model based on LSTM neural network in bridge health monitoring system was proposed in this paper. The model was established based on the TensorFlow framework, and RMSE and MAE were taken as evaluation parameters of prediction accuracy. The model was verified in the data of actual bridge monitoring. The main conclusions could be obtained as follows.

The RMSE and MAE of prediction results were 0.32Hz and 0.12Hz respectively, which indicated that the predicted value was basically the same as the actual value. Therefore, the model could meet the requirements of engineering accuracy.

The prediction error of LSTM model was -0.56%~0.60%, thus the prediction effect of LSTM neural network was stable in different periods.

Acknowledgments

The research described in this paper was financially supported by the China Postdoctoral Science Foundation (Granted No 2019M662917), the Science and technology planning project of Guangzhou
Municipal Construction Group Co., Ltd(Granted No [2019]-KJ023, [2020]-KJ009), Guangzhou science and technology projects (Granted No 2021-03-00-06-3002-0008), Innovation leadership team project of Baiyun district(2019), Science and Technology Program of the Ministry of Housing and Urban-Rural Development(Granted No 2020-K-130), the Foundation of Zhuhai Da Hengqin Co. Ltd and China railway 20 bureau group Co. Ltd (Granted No SG01-2018-458B).

References

[1] Azimi M, Eslamlou A D and Pekcan G 2020 Data-driven structural health monitoring and damage detection through deep learning: state-of-the-art review Sensors 20(10).

[2] Weinstein J C, Masoud S and Brenner B R 2018 Bridge damage identification using artificial neural networks Journal of Bridge Engineering 23(11) 04018084.

[3] Zhou Y, Zhu Y, Qiao S F, et al. 2020 Prediction method of monitoring data based on data association degree Science Technology and Engineering 22: 9128-9132. (in chinese)

[4] Luan Y Z, Ji Z L, Liang Y D, et al. 2020 Prediction and analysis of surface subsidence coefficient based on GRA-PCA-BP neural network model 2020 China Sciencepaper 15(09): 993-997+1004. (in chinese)

[5] Weinstein J C, Masoud S, Brenner B R 2018 Bridge damage identification using artificial neural networks Journal of Bridge Engineering 23(11): 04018084.

[6] Xi J and Fu L 2019 Analysis of deformation law of deep foundation pit based on space-time effect Science Technology and Engineering 19(16): 290-297. (in chinese)

[7] Ioffe S and Szegedy C 2015 Batch normalization: accelerating deep network training by reducing internal covariate shift 3:1-11.