Orbit Error Compensation Based on BiLSTM for Satellite Laser Ranging

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With the increasing number of space objects, space situational awareness (SSA) faces challenges in efficiently and accurately predicting the orbits of resident space objects (RSOs). Traditional physical model-based orbit prediction methods fail to achieve the precision required to avoid collisions. Here, collisions refer to those caused by RSO orbit prediction errors rather than external factors affecting space conditions.

This paper proposes an error compensation method based on the Bidirectional Long Short-Term Memory (BiLSTM) model, incorporating satellite laser ranging (SLR) data to correct orbits. The compensation method first obtains CPF files from https://ilrs.gsfc.nasa.gov, uses SLR observational data to generate reference orbits, and calculates propagation errors. By analyzing the dynamic characteristics of these errors, a 24-hour dataset is selected as the training set for the BiLSTM model, enabling the model to learn and predict the errors for each axis component. The BiLSTM model leverages its unique architecture to capture long-term dependencies in time series data and uses an attention mechanism to handle key information at critical time points. Finally, statistical analysis of the model's predictions and the propagation errors is conducted to calculate the error compensation rate and evaluate the method's performance.

Statistical analysis based on satellite laser ranging data shows that, over a one-year period, the compensated orbit errors are reduced by an average of approximately 28%. The errors of each component compensated by the BiLSTM model, as well as the errors of each component relative to the original propagation orbit, are categorized by month, and the median and mean for each month are calculated. The results are shown in Figure 1, where black represents the differences between the original propagation orbit and the reference orbit, and red represents the errors after compensation by the BiLSTM model. Theoretically, smaller errors represented by the red line indicate better learning performance of the model, suggesting that the compensation is more effective and the compensated propagation orbit is closer to the reference orbit. To more intuitively demonstrate the level of error compensation after BiLSTM model prediction, Figure 2 shows the percentage of position error after model compensation relative to the original propagation orbit error, categorized by month, and calculates the median and mean for each month. Theoretically, a higher compensation percentage means smaller errors in the compensated propagation orbit, indicating better compensation effectiveness. This study presents a new method for improving orbit prediction accuracy, which is of great significance for enhancing SSA capabilities, ensuring the safety of space operations, and effectively utilizing SLR observational data.

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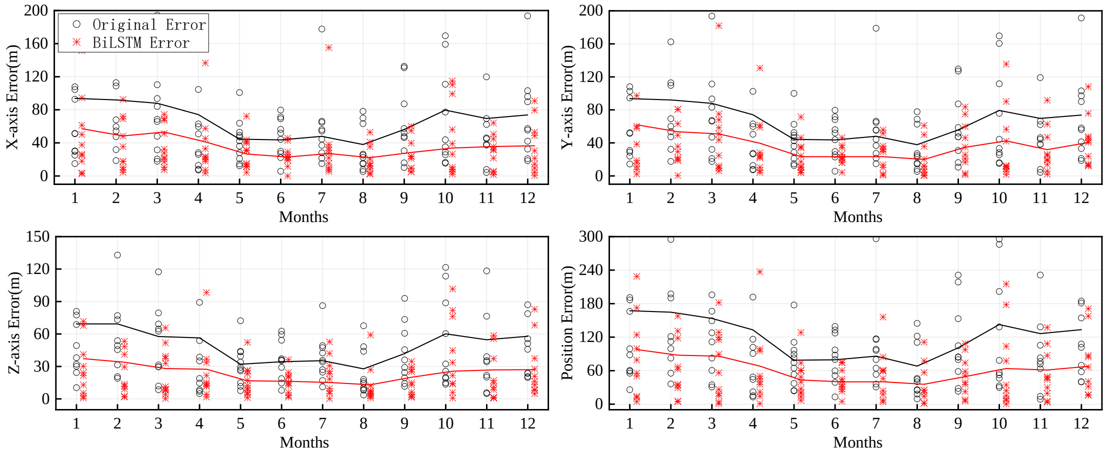

Figure 1. Compensation Effect of the Original Propagation Orbit.

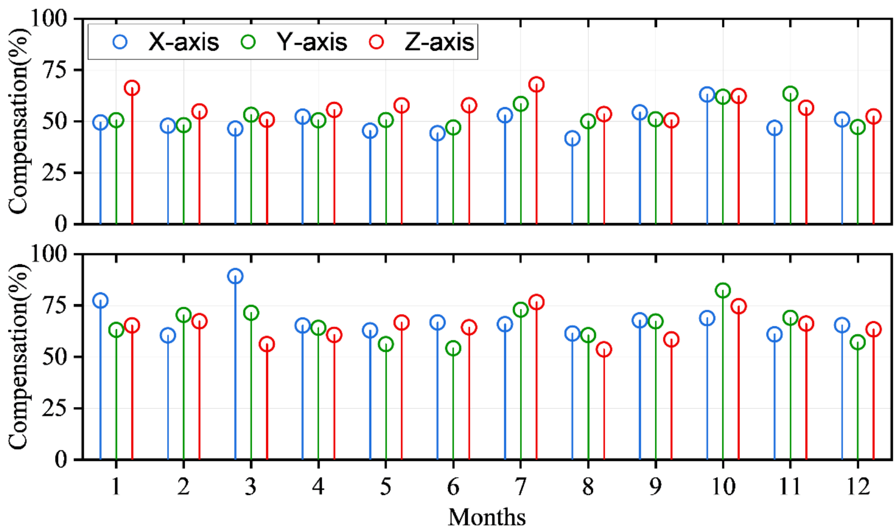

Figure 2. Error Compensation Effect for Different Components.