A Geometric Algebra-based Approach for Typhoon Intensity Forecasting

Monchi Li*

Department of Information Engineering, University of Nanjing, China

LiMonchi.dgrtjy@gmail.com

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Description

Typhoon intensity forecasting remains a critical challenge in meteorology, requiring sophisticated methods that can accurately predict the strength and trajectory of these powerful tropical cyclones. Traditional machine learning techniques have been employed with varying degrees of success, but they often struggle with the complex, nonlinear dynamics inherent in typhoon formation and evolution. A promising alternative approach involves leveraging Geometric Algebra (GA), a mathematical framework that unifies geometric and algebraic concepts, to develop a novel machine learning method tailored specifically for typhoon intensity forecasting. Geometric Algebra provides a powerful mathematical language for describing geometric objects and transformations, making it well-suited for modeling complex physical systems like typhoons. The GA-based machine learning method for typhoon intensity forecasting begins by representing meteorological data, such as atmospheric pressure, wind speed, temperature gradients, and sea surface temperatures, as multi vector entities within the GA framework. One of the key advantages of using GA is its ability to handle multidimensional data and capture geometric relationships in a concise and intuitive manner. By encoding meteorological variables as multi vectors, the GA-based method captures the spatial and temporal interactions among different atmospheric parameters, allowing for a more comprehensive representation of the underlying physical processes driving typhoon intensity. The GA-based machine learning model employs a combination of supervised learning techniques, such as Support Vector Machines (SVMs) or neural networks, along with GA-based feature engineering and dimensionality reduction methods. These techniques extract meaningful geometric features from the data and transform them into a lower-dimensional representation that retains essential information for forecasting typhoon intensity. The feature extraction process involves constructing multi vector representations of meteorological variables and applying geometric operations such as inner products, outer products, and geometric products to extract relevant patterns and structures. This geometric feature engineering step enhances the model's ability to capture nonlinear relationships and spatial dependencies in the data, which are crucial for accurate forecasting. Additionally, the GA-based method incorporates physical principles and domain knowledge into the machine learning framework. For example, it can incorporate conservation laws, atmospheric dynamics equations, and thermodynamic principles as constraints or regularization terms during the learning process. This integration of physics-based constraints enhances the model's interpretability, robustness, and generalization capabilities. Furthermore, the GA-based approach facilitates the integration of satellite imagery, radar data, and Numerical Weather Prediction (NWP) models into the forecasting pipeline. By leveraging GA's versatility in handling diverse data types and formats, the method can assimilate real-time observational data and high-resolution simulations, improving the accuracy and reliability of intensity forecasts. The training and validation of the GA-based machine learning model involve optimizing model parameters, selecting appropriate geometric features, and fine-tuning the learning algorithms to minimize prediction errors. Cross-validation techniques, ensemble methods, and model fusion strategies may also be employed to enhance predictive performance and mitigate overfitting. The effectiveness of the GA-based machine learning method for typhoon intensity forecasting is evaluated through comprehensive validation against historical typhoon datasets, including observed intensity measurements and actual storm tracks. The model's performance metrics, such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and correlation coefficients, are compared with baseline models and traditional machine learning approaches to assess its predictive accuracy and reliability. In conclusion, the Geometric Algebra-based machine learning method represents a promising paradigm for enhancing typhoon intensity forecasting capabilities. By leveraging GA's geometric and algebraic properties, the method captures complex interactions and patterns in meteorological data, leading to more accurate and interpretable intensity forecasts. This innovative approach holds the potential to advance our understanding of tropical cyclone dynamics and improve early warning systems for vulnerable coastal regions.

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Conflict of Interest

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