Predicting Ocean Wave Heights using Numerical Methods and RNN-Based Models

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1. Introduction

The prediction of ocean wave heights is essential for ensuring maritime safety, disaster preparedness, and improving navigation efficiency. This study focuses on predicting the maximum wave height using two approaches: a basic Numerical Method (Euler's Method) and RNN-based machine learning models (LSTM, GRU, and Bi-GRU).

2. Data Collection

The data used for this analysis was collected from Marine Meteorological Buoys deployed by the Korean Meteorological Administration. These buoys measure and transmit data such as:

- Wind Speed (m/s)
- Water Temperature (°C)
- Maximum Wave Height (m)
- Significant Wave Height (m)
- Wave Period (sec)   etc

The dataset spans from January 1, 2024, to December 13, 2024, covering 31 monitoring stations. (totally 242504 data)

Fig.1. wave monitoring buoy

```
file_path = '/content/OBS_BUOY_TIM_20241214230227.csv'
df =  pd.read_csv(file_path, encoding='cp949')  # 또는 'euc-kr'
df.head()
```

	지점	일시	풍속(m/s)	풍향(deg)	현지기압(hPa)	습도(%)	기온(° C)	수온(° C)	최대파고(m)	유의파고(m)	평균파고(m)	파주기(sec)	파향(deg)
0	21229	2024-01-01 0:00	12.8	11.0	1024.1	65.0	7.0	15.1	6.0	3.8	2.7	9.1	42.0
1	21229	2024-01-01 1:00	11.7	12.0	1024.9	66.0	6.3	15.1	6.4	3.5	2.5	7.1	23.0
2	21229	2024-01-01 2:00	9.9	10.0	1025.8	59.0	4.2	15.2	6.6	3.8	2.7	9.1	27.0
3	21229	2024-01-01 3:00	10.1	6.0	1026.2	60.0	3.9	15.3	6.5	4.3	3.1	9.1	44.0
4	21229	2024-01-01 4:00	9.5	3.0	1026.3	59.0	6.0	15.3	6.4	4.4	3.2	9.1	22.0

Fig.2. overview of the data

3. Numerical Method

To establish a baseline, Euler's method was used to approximate the changes in wave height over time. The governing differential equation is given by:

$$dh/dt = \alpha \bullet U - \beta \bullet h$$

$$h(t+1) = h(t) + \Delta t \bullet dh/dt$$

Where:
- h: Maximum wave height
- U: Wind speed
- α: Coefficient for wind speed effect
- β: Coefficient for natural damping.

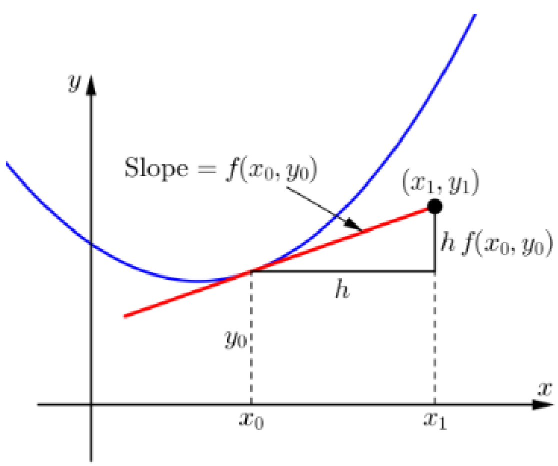


Fig.3. Euler method

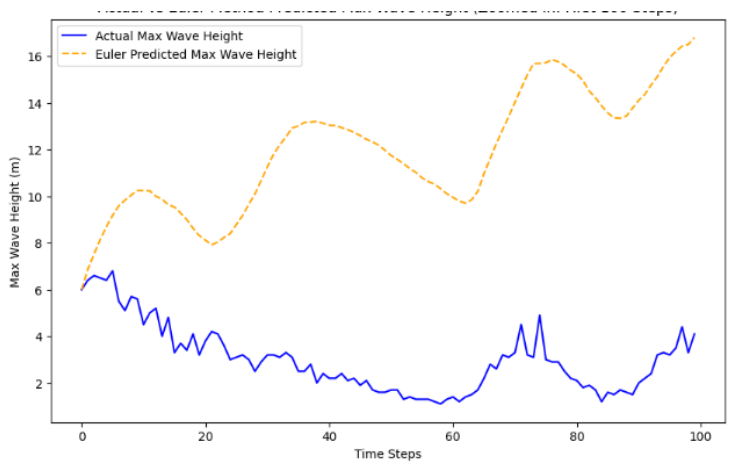


Fig.4. Results of naïve Euler method

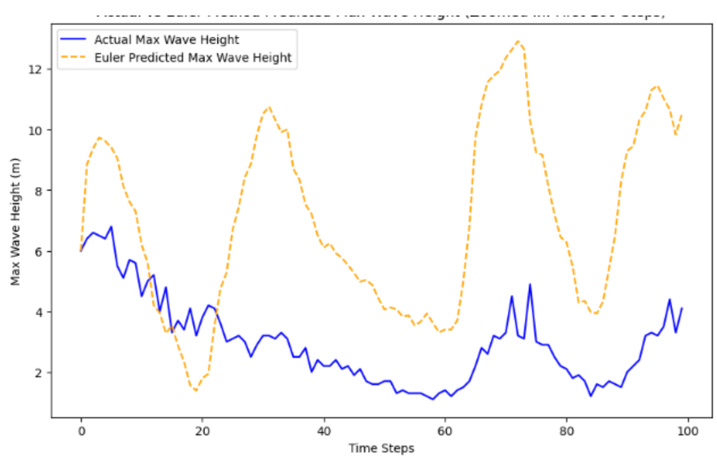


Fig.5. Results of optimized Euler method

Results with Euler's Method

• Naïve Approach: Predictions showed low accuracy due to the simplicity of the method.
• Optimized Approach: Using parameter tuning (e.g., Grid Search) improved the results, but limitations still remained.

4. Machine Learning Models

To overcome the limitations of numerical methods, RNN-based machine learning models were employed. The following architectures were tested:

1. RNN: Handles sequential data but suffers from the vanishing gradient problem.
2. LSTM: Mitigates RNN's limitations using gates (forget, input, output gates).
3. GRU: A simplified version of LSTM with fewer parameters.
4. Bi-GRU: Processes data in both forward and backward directions.

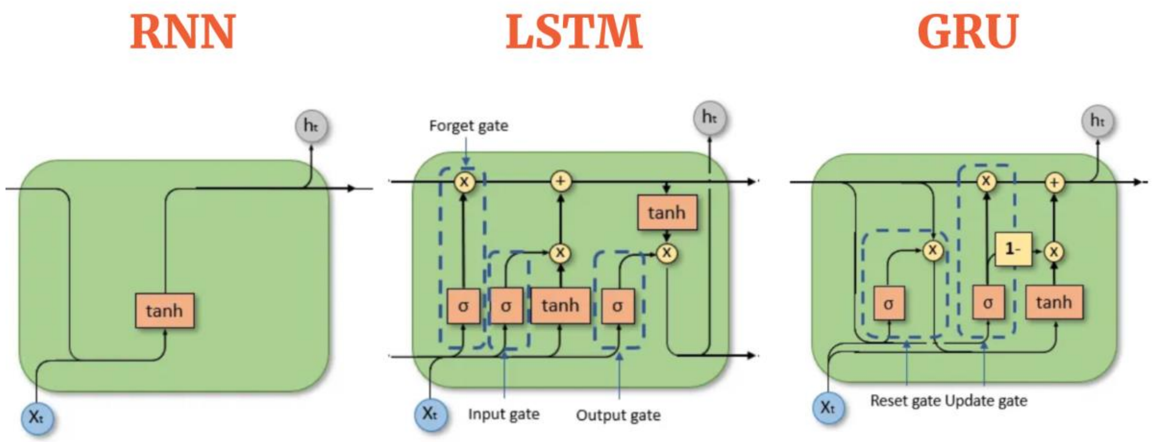
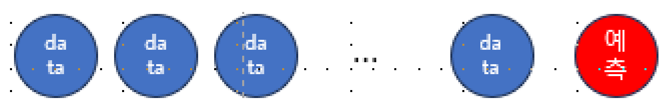


Fig.6. RNN based models

5. Code Implementation

The pipeline included data preprocessing, sequence preparation, model training, and testing. Sequence length was set to 36 time steps, and data was split into 80% for training and 20% for testing.



6. Results

Model	Error (E)
LSTM	0.1772 m
GRU	0.1814 m
Bi-GRU	0.1843 m

LSTM achieved the lowest error but required significantly more computation time. GRU balanced accuracy and efficiency, while Bi-GRU showed minimal improvement.

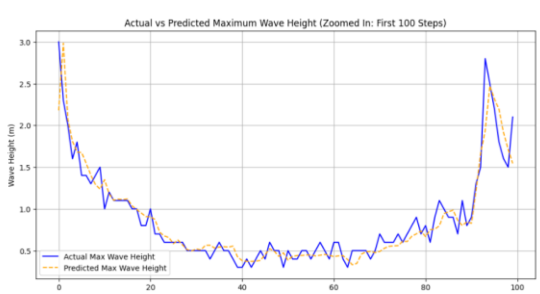


Fig.6. LSTM

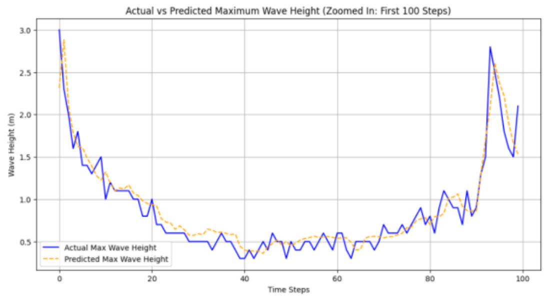


Fig.7. GRU

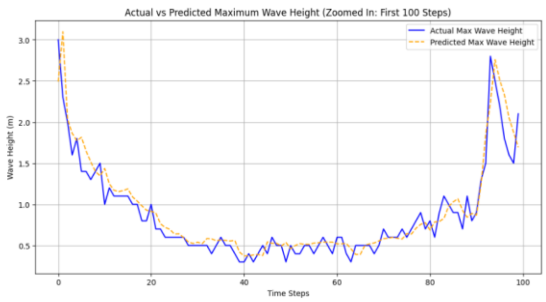


Fig.8. BI-GRU

7. Conclusion

GRU was the most practical model for predicting ocean wave heights due to its accuracy and computational efficiency. Future work includes integrating domain-specific knowledge, ensemble modeling, and broader dataset validation.