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Proposed Deep Learning Regression Model for Mapping and Monitoring Mangrove Canopy Height Over Large Areas Using Remote Sensing Data

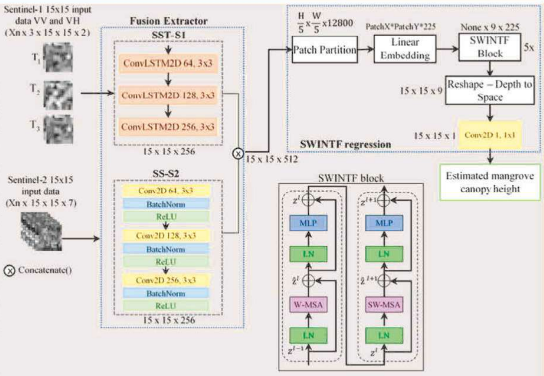
Ilham Jamaluddin, 3rd year Ph.D Student; Advisors: Prof. Kuo-Chin Fan and Dr. Ying-Nong Chen
Department of Computer Science and Information Engineering, National Central University, Taiwan

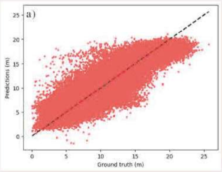
ABSTRACT

Mangroves are coastal vegetation and are considered one of the blue carbon ecosystems with a high carbon storage capacity. Mangrove canopy height is one of the important parameters related to the above-ground biomass and carbon stock information. Remote sensing data has been widely used for mangrove canopy height estimation. This study focused on developing deep learning regression model to improve the quality of mangrove canopy height mapping and monitoring over large areas using remote sensing data. This research uses Sentinel-2 optical image and time-series data from Sentinel-1 SAR image as the input dataset and uses the canopy height model data from LiDAR as the target data. The proposed model was tested on two datasets collected from Florida: large dataset for the Everglades National Park (ENP) and small dataset for the Charlotte Harbor Preserve State Park (CHPSP). The experimental results showed that the proposed model outperformed other regression models in terms of model's performance for mangrove canopy height mapping.

RESULTS

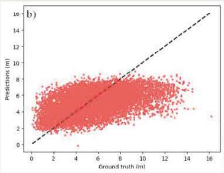
This study developed a spatial-spectral-temporal deep learning regression model with convolutional long short-term memory (ConvLSTM) and transformer (hereafter referred to as the SST-CLT model) to map mangrove canopy height over large area. The SST-CLT model consists of two sub-models trained simultaneously. The SST-CLT model considered the spatial-spectral-temporal correlation of Sentinel-1 time series and Sentinel-2 data. In general, the SST-CLT has two sub-model: 1) fusion extractor sub-model that consists of SST-S1 extractor part and SS-2 extractor part, 2) SWINTF regressor sub-model that exploit the advantages of Swin transformer model.





Height (m)	Total Test Samples (pixels)	Avg. MAE (m)	Avg. RMSE (m)
0 – 5	5761	2.239	2.822
5 – 10	18779	1.696	2.235
10 – 15	17007	1.977	2.466
15 – 20	12444	1.442	1.888
> 20	2034	3.073	3.287

TABLE IV
AVERAGE MAE VALUES OBTAINED WITH THE SST-CLT MODEL FOR VARIOUS HEIGHT RANGES IN THE ENP DATASET



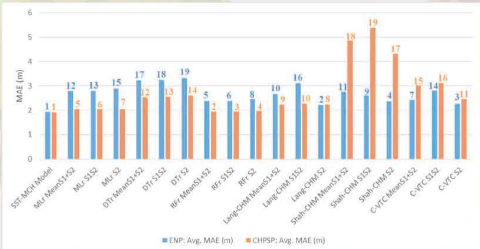
Height (m)	Total Test Samples (pixels)	Avg. MAE (m)	Avg. RMSE (m)
0 – 5	4480	1.495	1.828
5 – 10	5663	1.738	2.134
10 – 15	656	5.251	5.438
15 – 20	1	12.774	12.774
> 20	0	0	0

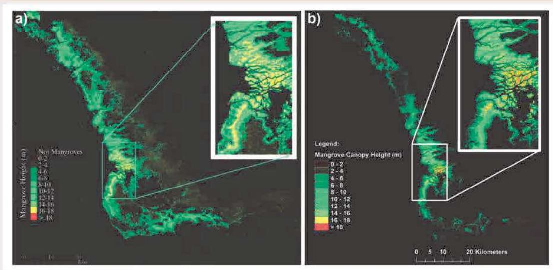
TABLE V
AVERAGE MAE VALUES OBTAINED WITH THE SST-CLT MODEL FOR VARIOUS HEIGHT RANGES IN THE CHPSP DATASET

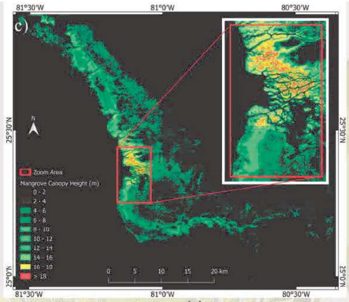
For the ENP dataset (large dataset), the proposed model exhibited average MAE and RMSE values of 1.924 and 2.471 m, respectively. Moreover, for the CHPSP dataset (small dataset), the proposed model exhibited average MAE and RMSE values of 1.913 and 2.440 m, respectively.

The Scatter plot of the ground-truth LiDAR CHM data (testing data) versus the prediction results: the (a) ENP and (b) CHPSP. The testing data were divided using 5-m intervals. For the ENP dataset, the lowest average MAE (1.442 m) was obtained at a mangrove canopy height of 15–20 m. For the CHPSP dataset, the lowest average MAE (1.495 m) was obtained for a canopy height of 0–5 m.

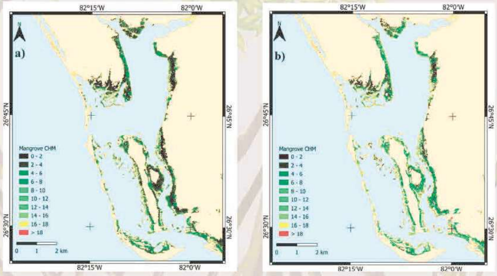
The ranking of the compared models in terms of average MAE for the ENP and CHPSP datasets is shown in this figure. For both datasets, the SST-CLT model outperformed the other regression models in terms of the average MAE and RMSE values.







Maps of mangrove canopy heights in the ENP at different times: (a) during 2000–2004 at a spatial resolution of 30 m (published by Simard et al. 2011), (b) during 2011–2014 at a spatial resolution of 12 m (published by Feliciano et al. 2017), and (c) in 2017 at a spatial resolution of 10 m (obtained using the proposed model). A visual comparison of the three maps indicated that the three maps exhibited similar patterns in mangrove height. The mangrove canopy height in the SRS region (zoomed-in area) increased from 2000 to 2017. In 2000, this region mostly had a mangrove canopy height of approximately 14–16 m. In 2014, the mangrove canopy height was still mainly 14–16 m; however, many mangroves taller than 18 m were detected. In addition, the number of mangroves taller than 18 m increased further between 2014 and 2017.



Comparison of the mangrove canopy heights obtained for the CHPSP in the present study and a previous study: (a) map for 2017 with a spatial resolution of 10 m that was obtained in the present study and (b) map for 2000–2009 with a spatial resolution of 30 m that was obtained by Simard et al. 2011.

CONCLUSION

Based on the experimental results, the SST-CLT model successfully combined Sentinel-1 time-series data with Sentinel-2 data as input data. The testing results revealed that the average MAE of the mangrove canopy heights obtained using the proposed model was 1.924 and 1.913 m for the ENP and CHPSP datasets, respectively. Finally, this study investigated the mangrove canopy height in the entire areas of the ENP and CHPSP in 2017 at a spatial resolution of 10 m. According to the obtained mangrove canopy height maps, the average mangrove canopy heights in the ENP and CHPSP were 7.68 and 4.381 m, respectively.

SELECTED PUBLICATIONS

•Ilham Jamaluddin, Ying-Nong Chen, Kuo-Chin Fan. "Spatial–Spectral–Temporal Deep Regression Model With Convolutional Long Short-Term Memory and Transformer for the Large-Area Mapping of Mangrove Canopy Height by Using Sentinel-1 and Sentinel-2 Data", IEEE Transactions on Geoscience and Remote Sensing (Volume: 62, 2024).
•Ilham Jamaluddin, Tipajin Thaipisutikul, Ying-Nong Chen, Chi-Hung Chuang and Chih-Lin Hu. "MDPrePost-Net: A Spatial-Spectral-Temporal Fully Convolutional Network for Mapping of Mangrove Degradation Affected by Hurricane Irma 2017 using Sentinel-2 Data", Remote Sensing (2021).
•Muhammad Dimyati, Deha Agus Umarhadi, Ilham Jamaluddin, Disyacitta Awanda, WiwidWidyatmanti. "Mangrove monitoring revealed by MDPrePost-Net using archived Landsat imageries", Remote Sensing Applications: Society and Environment (2023).

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