Landslide Detection with U-net Based SAR2OPT Framework : A Case Study of 2024 Hualien Earthquake

Wen-Hong Chen. 1*, Shou-Hao Chiang. 2

1Department of Civil Engineering, National Central University , Taiwan

2Center for Space and Remote Sensing Research, National Central University , Taiwan

c113322091@g.ncu.edu.tw

Abstract : *The 2024 Hualien earthquake caused multiple landslide, highlighting the need for dependable and rapid disaster detection. Synthetic Aperture Radar (SAR) offers an all-weather means of observation, making it a staple in remote-sensing studies. Yet, because SAR data lack the rich color and fine texture of optical imagery, extracting landslide information from them alone remains difficult. In this study, we embedded the modified U-net framework that combined four bands Sentinel-1 imagery, including VV and VH polarization data from ascending and descending observations. Fusing both orbits mitigates geometric layover and shadowing in rugged terrain, thereby preserving surface backscatter integrity. A sliding-window scheme with overlapping patches is employed during the training phase to preserve spatial context and minimize edge discontinuities between patches; specifically, 128 × 128 patches with a 64-pixel overlap and 256 × 256 patches with a 128-pixel overlap were tested. After end-to-end training, the model can rapidly produce optical-like NDVI maps directly from dual-orbit Sentinel-1 SAR imagery, offering an alternative for post-earthquake surface monitoring when optical data are not timely available. This study adopts the April 2024 Hualien earthquake in northeastern Taiwan as its testbed. The goal is to verify whether the SAR-derived optical products maintain enough spatial detail and spectral fidelity to support landslide mapping, paving the way for their fusion with machine-learning models in fully automated landslide detection.*

Keywords: SAR2OPT , Landslide Detection , Synthetic Aperture Radar , U-net , Hualien Earthquake

1. Introduction

The April 3, 2024 Hualien earthquake (Mw 7.2) triggered widespread landslides in eastern Taiwan, highlighting the urgent need for rapid post-disaster detection. While optical imagery provides vegetation indices such as NDVI, its availability is often limited by cloud cover (Flores-Anderson et al., 2023; Novellino et al., 2024). By contrast, Synthetic Aperture Radar (SAR) offers all-weather imaging and has been widely applied for landslide mapping, though intensity-only features are sensitive to speckle and terrain-induced distortions (Santangelo et al., 2022). Multi-orbit fusion and terrain attributes such as slope and aspect have been shown to improve robustness in mountainous terrain (Pan & Shi, 2023).

Recent studies demonstrate that deep learning, particularly U-net architectures, outperform traditional pipelines for pixel-wise landslide detection (Yang et al., 2024). Beyond direct SAR-based mapping, SAR-to-optical translation and SAR-derived NDVI estimation have emerged as promising strategies, providing vegetation-sensitive proxies when cloud-free optical data are delayed (Guo et al., 2024; Roßberg & Schmitt, 2023).

In this context, we propose a SAR-to-NDVI (SAR2NDVI) framework that fuses dual-orbit Sentinel-1 VV/VH with local statistics and DEM-based encodings. The goal is to reconstruct optical-like NDVI at 10 m resolution, enabling timely and interpretable landslide detection following the 2024 Hualien earthquake.

2. Methodology

This study focuses on landslides triggered by the April 3, 2024 Hualien earthquake in Taroko National Park, Taiwan. Dual-orbit Sentinel-1 GRD backscatter (VV/VH) data were used as inputs, co-registered with Sentinel-2 NDVI for reference. Terrain attributes (slope/aspect) were derived from the ALOS DEM and resampled to 10 m.

The preprocessing pipeline includes: (i) imputation of isolated No Data pixels, (ii) orbit-wise averaging to fuse ascending and descending scenes, (iii) extraction of local mean and standard deviation to stabilize speckle, and (iv) normalization of all channels. Together with DEM-based encodings—sin(aspect), cos(aspect), sin(slope)—this yields a 9-channel input stack.

A U-net model was trained with 128×128 patches (64-pixel overlap), optimized by a composite loss (L1 + SSIM + gradient). The trained network directly regresses NDVI values in the range [−1, 1]. Model performance was evaluated against Sentinel-2 NDVI using RMSE, MAE, SSIM, and PSNR.

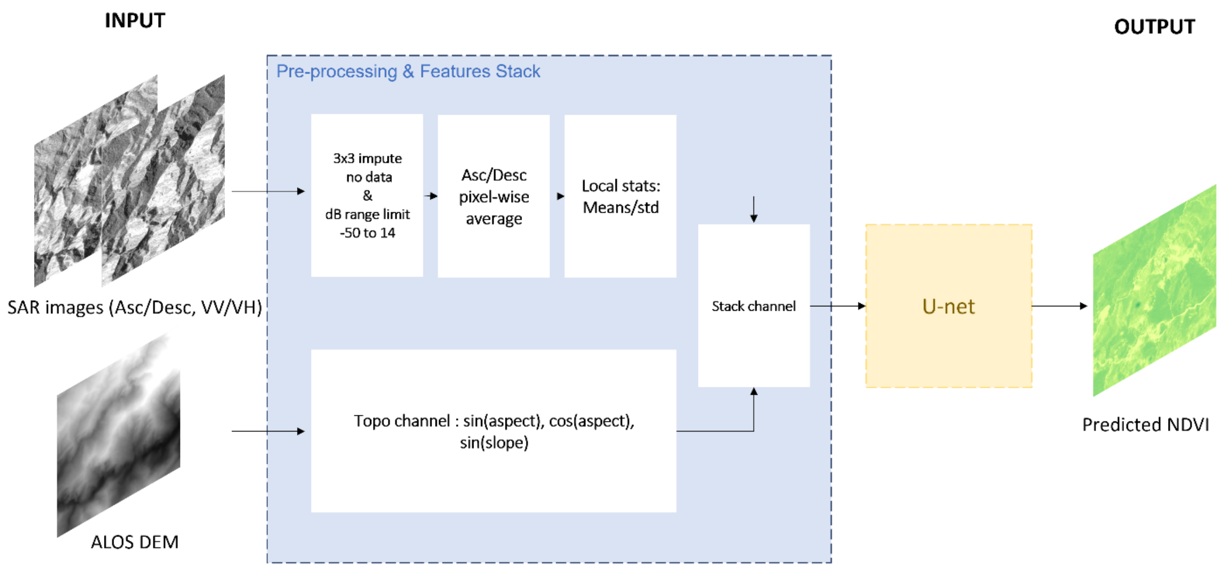


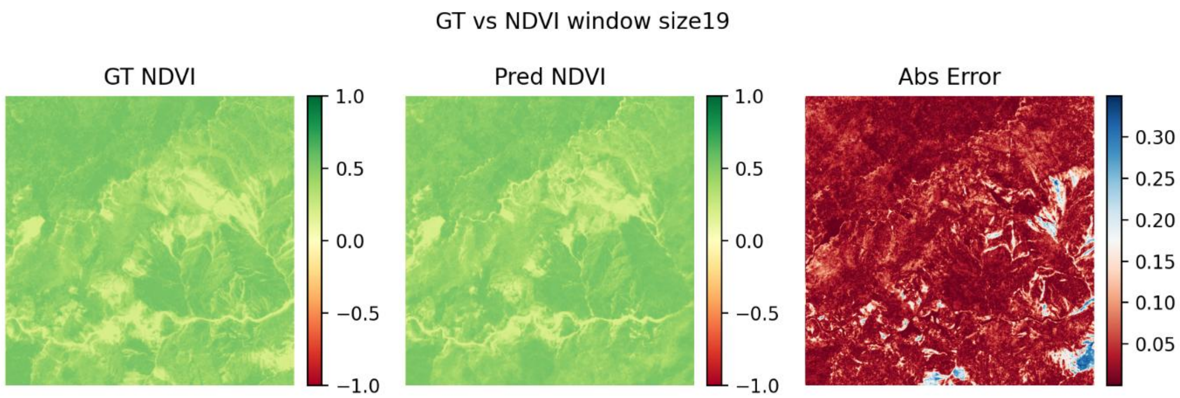
Figure 1: structure of the model

3. Results/Findings

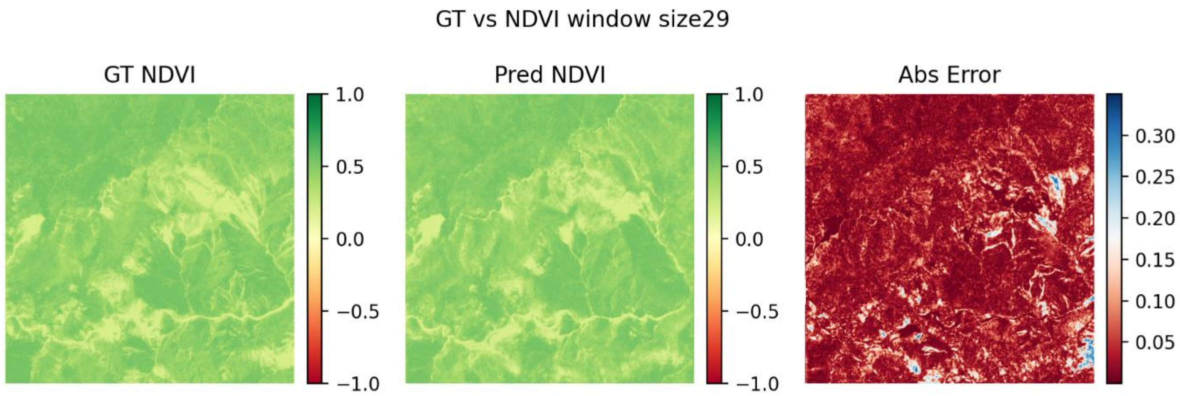
The proposed SAR-to-NDVI framework achieved stable performance across the Hualien earthquake test area, with average metrics of RMSE = 0.0615, MAE = 0.0423, SSIM = 0.826, and PSNR = 30.25 dB against co-registered Sentinel-2 NDVI.

A kernel-size sensitivity analysis revealed a trade-off: larger windows (e.g., 29×29) emphasized denoising and yielded the lowest RMSE and highest PSNR, while mid-sized kernels (e.g., 19×19) preserved sharper boundaries, producing the highest SSIM and lowest MAE. Patch size experiments showed that 128×128 tiles offered a better balance than 256×256, which did not improve accuracy and slightly reduced structural fidelity; thus, the 256×256 setting was not included in the final comparison.

Qualitative inspection confirmed these trends: predicted NDVI maps effectively captured vegetation contrasts and landslide boundaries, with residual errors concentrated in shadow/layover zones and newly disturbed debris. These results indicate that the framework can provide reliable vegetation-sensitive proxies for rapid post-earthquake landslide detection.



(a)



(b)

Figure 2: Qualitative comparison of ground-truth NDVI, predicted NDVI, and absolute error for two local-statistics kernels: (a) 19×19 and (b) 29×29

Table 1. Effect of local-statistics window size on accuracy.

Window size	RMSE	MAE	SSIM	PSNR (dB)
11	0.0609	0.0431	0.8224	30.34
13	0.0613	0.0414	0.8251	30.27
15	0.0611	0.0414	0.8327	30.31
17	0.0614	0.0426	0.8244	30.26
19	0.0617	0.0406	0.8522	30.22
21	0.0622	0.0438	0.8243	30.15
23	0.0619	0.0426	0.8253	30.19
25	0.0626	0.0435	0.8178	30.09
27	0.0620	0.0425	0.8094	30.17
29	0.0596	0.0410	0.8290	30.51

4. Conclusion

This study demonstrates that a compact U-net–based SAR-to-NDVI framework can effectively reconstruct vegetation indices from dual-orbit Sentinel-1 imagery in mountainous terrain. By integrating local statistics and DEM-derived encodings, the model achieved stable accuracy (RMSE ≈ 0.0615, MAE ≈ 0.0423, SSIM ≈ 0.826, PSNR ≈ 30.25 dB) and successfully delineated landslide boundaries following the April 3, 2024 Hualien earthquake**.**

A kernel-size sensitivity analysis revealed a trade-off between noise suppression and structural fidelity, with **19×19 windows** offering sharper edge representation for landslide mapping, while **29×29 windows** reduced pixel-wise errors. Larger training patches (256×256) provided no consistent improvement and were excluded from the final comparison.

Overall, the framework provides a lightweight and operational tool for post-earthquake landslide detection when optical imagery is not available. Future work will focus on extending the approach to multi-event validation and integrating with operational landslide mapping workflows.

References

Flores-Anderson, A. I., Cardille, J., Azad, K., Cherrington, E., Zhang, Y., & Wilson, S. (2023). Spatial and temporal availability of cloud-free optical observations in the tropics to monitor deforestation. Scientific Data, 10, 550. https://doi.org/10.1038/s41597-023-02439-x

Santangelo, M., Cardinali, M., Bucci, F., Fiorucci, F., & Mondini, A. C. (2022). Exploring event landslide mapping using Sentinel-1 SAR backscatter products. Geomorphology, 397, 108021. https://doi.org/10.1016/j.geomorph.2021.108021

Pan, B., & Shi, X. (2023). Fusing ascending and descending time-series SAR images with dual-polarized pixel-attention U-Net for landslide recognition. Remote Sensing, 15(23), 5619. https://doi.org/10.3390/rs15235619

Lee, M. A., Aanstoos, J. V., Bruce, L. M., & Prasad, S. (2012). Application of omni-directional texture analysis to SAR images for levee landslide detection. In 2012 IEEE International Geoscience and Remote Sensing Symposium (IGARSS) (pp. 1805–1808). https://doi.org/10.1109/IGARSS.2012.6351161

Yang, Z.-Q., Qi, W.-W., Xu, C., & Shao, X.-Y. (2024). Exploring deep learning for landslide mapping: A comprehensive review. China Geology, 7(2), 330–350. https://doi.org/10.31035/cg2024032

Shi, H., Cui, Z., Chen, L., He, J., & Yang, J. (2024). A brain-inspired approach for SAR-to-optical image translation based on diffusion models. Frontiers in Neuroscience, 18, 1352841. https://doi.org/10.3389/fnins.2024.1352841

Roßberg, T., & Schmitt, M. (2023). A globally applicable method for NDVI estimation from Sentinel-1 SAR backscatter using a deep neural network and the SEN12TP dataset. PFG—Journal of Photogrammetry, Remote Sensing and Geoinformation Science, 91, 171–186. https://doi.org/10.1007/s41064-023-00238-y

Chen, D., Hu, H., Liao, C., Ye, J., Bao, W., Mo, J., ... Pei, J. (2023). Crop NDVI time series construction by fusing Sentinel-1, Sentinel-2, and environmental data with an ensemble-based framework. Computers and Electronics in Agriculture, 215, 108388. https://doi.org/10.1016/j.compag.2023.108388

Guo, Z., Liu, J., Cai, Q., Zhang, Z., & Mei, S. (2024). Learning SAR-to-optical image translation via diffusion models with color memory. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 17, 14454–14470. https://doi.org/10.1109/JSTARS.2024.3439516

Novellino, A., Pennington, C., Leeming, K., Taylor, S., González Álvarez, I., McAllister, E., Arnhardt, C., & Winson, A. (2024). Mapping landslides from space: A review. Landslides, 21, 1041–1052. https://doi.org/10.1007/s10346-024-02215-x

Amatya, P., Kirschbaum, D., & Stanley, T. (2019). Use of very high-resolution optical data for landslide mapping and susceptibility analysis along the Karnali Highway, Nepal. Remote Sensing, 11(19), 2284. https://doi.org/10.3390/rs11192284