Mind The Slick: Adaptation of Attention U-Net for Satellite-Based Ocean Oil Spill Detection

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GitHub: https://github.com/nicholas-tobias-00/attention_unet_for_oil_spill

Original Paper

This project builds on top of John D. and Zhang C. (2022) paper on deforestation segmentation [1]. The paper outlines several key concepts:

1. Introduces the Attention U-Net architecture that in theory improves focus on relevant spatial features (forest / non-forest) for segmentation.
2. Pursues environmental monitoring by detecting deforestation.
3. Establishes the baseline result between multiple convolution models, with Attention U-Net having the best scores.

Relevant SDGs

Primary (15.1, 15.2, 15.5)
monitoring land-cover change and tracking deforestation.

Primary (13.1 and 13.2)
provides data for land-use and detect environmental changes early.

Primary (12.2 and 12.6)
transparent land use monitoring and accountability for industries linked to deforestation

Secondary (9.5)
Supporting research and innovation in remote sensing and AI.

Reproduced Metrics and Sample Prediction

Baseline vs Reproduced	Accuracy	Precision	Recall	F1
Baseline	97.5%	97.6%	97.5%	97.5%
Reproduced	97%	98.1%	95.9%	97%

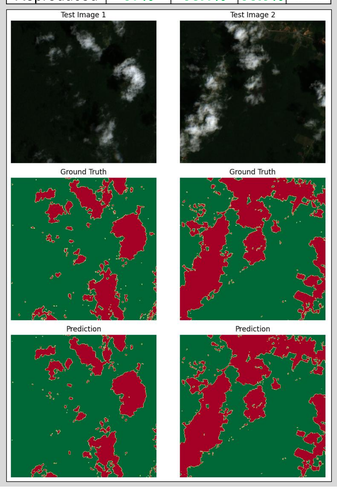

Figure 1 (Clockwise Order): Training Curve and Relevant SDGs, Metrics Comparison, and Sample Predictions for Reproduced Model (epoch = 50)

New Context

Stemming from the success of the deforestation detection with Attention U-Net, we push our focus to oil spill segmentation, a task equally critical given that:

1. Ocean life is critical to humanity, based on UN's Food and Agriculture Organization report:
   1. Supports the livelihood of more than 3 billion people
   2. Produces 50% of earth's O2
   3. Absorbs 30% of earth's CO2
2. Oil spills severely damage the ecosystem by killing marine life directly, as well as poison their habitats for years, potentially leading to a change in the food chain.
3. The monitoring of oceans is very difficult given that it encompasses two-thirds of the earth's surface. With most ocean territory being international waters, it is also extremely hard to enforce laws over oil spills.

These challenges point to the need for automated ocean monitoring, and Attention U-Net provides a strong solution by being able to focus on subtle patterns while suppressing the many irrelevant background noise of the ocean.

Datasets, Adaptation, and Model Architecture

This project utilizes the same principle of John D. and Zhang C. (2022)'s deforestation paper with two significant modifications:

I. Dataset modifications

- The original dataset used for deforestation mapping is replaced with Sentinel-1 GRD ocean imagery, requiring adjustments in preprocessing steps
- The project uses a labeled oil spill dataset from previous work by Trujillo-Acatitla et al. (2024) [2]. In detail, the following data has been provided:
  - 3,020 labelled oil spill data with
  - Out of 3,020 labelled data:
    - 1,350 oil images
    - 1,520 not oil images, with 835 being a lookalike
- Additional data can be processed by downloading high resolution Sentinel-1 GRD images in dual polarization (IW mode, VV, VH) images from **ASF DAAC / Copernicus Open Access Hub** and then performing the following **processing with SNAP (SeNtinel Applications Platform)**:

Figure 2 : Sentinel-1 GRD Image Processing Pipeline with SNAP

II. Model Modifications

- Dataset balancing through training with weighted binary cross entropy loss function has been applied. This counters the small proportion of oil spills compared to the background.
  - → This ensures the overall training process to focus more on detected oil spills and preventing a lazy network from predicting "all ocean".
  - → Ablation study has been conducted in which weighted BCE shows significant improvement over unweighted.

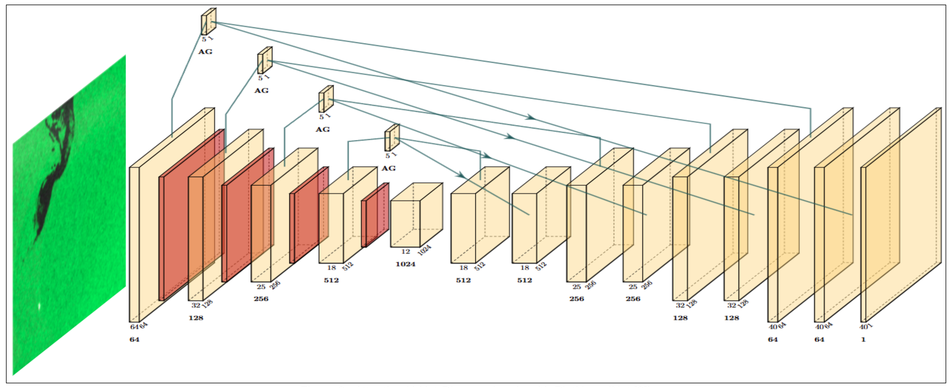

Figure 3 : Attention U-Net Diagram (made with PlotNeuralNet [3])

Training Information

- Dataset split for train / validation / test split : 2,184 / 386 / 450 (72% / 13% / 15%)
- Total dataset size : 127 GB
- Final training has been conducted with an RTX 5070:
  - Total runtime : 4.5 hours
  - Epoch : 20
  - Learning Rate : 1e-4

Model Performance and Evaluation

The proposed Attention U-Net architecture is implemented with the following results:

Metrics	BCE	Weighted BCE
Accuracy:	97.9%	**98.3%**
Precision:	87.6%	**74.1%**
Recall:	29.1%	**58.8%**
F1-Score:	43.7%	**65.6%**
IoU:	28.0%	**48.8%**

Key Observations (after 20 epochs):

1. Weighted BCE helps address imbalanced dataset, increasing recall and IoU significantly
2. Model achieved high accuracy, but scores lower on other metrics.
   - → Accuracy is high as "no oil" cases are abundant.
   - → Model can detect oil spills correctly but still requires improvement in its segmentation quality.

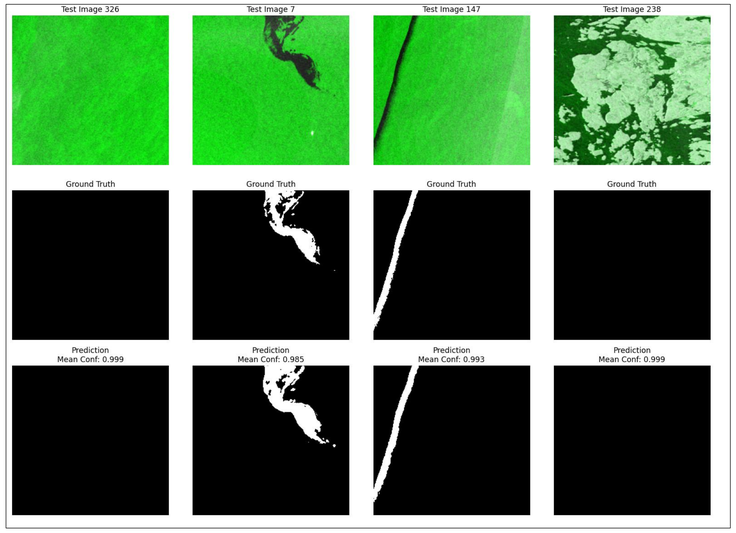

Figure 4: Oil Spill Detection Test Metrics and Sample Predictions

Reflection on Sustainable Development Goals

This project shows the use of AI and satellite imagery to support environmental protection. Using Attention U-Net for oil spill detection aligns the work with key SDGs, demonstrating how digital innovation improves monitoring and strengthens climate resilience.

Primary SDG – 14: Life Below Water (14.1, 14.2, 14.A)
- **14.1**: Reducing marine pollution by early oil spill detection.
- **14.2**: Supports protection of marine ecosystem by monitoring.
- **14.A**: Contributes to enhancing ocean science.

Primary SDG – 13: Climate Action (13.1, 13.2, 13.3)
- **13.1**: Increasing resilience and adaptive capacity to climate-related hazards.
- **13.2**: Provides data to support further climate action or policies.
- **13.3**: Provides foundation for autonomous monitoring and awareness of oil spills.

Primary SDG – 12: Responsible Consumption and Production (12.4, 12.6)
- **12.4**: Supports safe management of toxics and chemicals by autonomous monitoring and early detection.
- **12.6**: Encourages companies to adopt sustainable practice by raising accountability.

Possible Negative SDG Interactions:
- **SDG 7.2**: Increased energy usage for model training
- **SDG 8.5**: Automation of monitoring tasks may reduce certain job roles.
- **SDG 9.1**: Heavy reliance on advanced compute and satellite systems may widen technological inequalities.

References:

[1]. John, D. & Zhang, C. (2022) 'An attention-based U-Net for detecting deforestation within satellite sensor imagery', *International Journal of Applied Earth Observations and Geoinformation*, 107, p. 102685.

[2]. Trujillo-Acatitla, R., Tuxpan-Vargas, J., Ovando-Vázquez, C. & Monterrubio-Martínez, E. (2024) 'Marine oil spill detection and segmentation in SAR data with two steps Deep Learning framework', *Marine Pollution Bulletin*, 204, p. 116549.

[3]. HarisIqbal88. (n.d.). *PlotNeuralNet* [Computer software]. GitHub. https://github.com/HarisIqbal88/PlotNeuralNet/tree/master