TRACE: An approach to detect, track and monitor large floating marine litter in our seas

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Introduction

Marine debris is a severe environmental problem. It originates from many sources and causes a wide spectrum of environmental, economic, safety, health and cultural impacts. Millions of tonnes enter the oceans every year and tackling the issue is gaining momentum at all levels.

The goal of our project is to investigate the possibilities of detecting large floating debris with a multi-step approach, using image classification as well as object segmentation and tracking (Figure 1). We are interested to obtain reliable data on quantity, accumulation zones, temporal dissemination, material properties and potential sources of litter. This objective is achieved by building a system capable to process and analyse large amounts of remote sensing data and and by providing tools to gain insights into the obtained data.

In order to test our approach, we selected a study area and temporal season that is known to be affected by marine litter in the Northern Adriatic Sea (Figure 4).

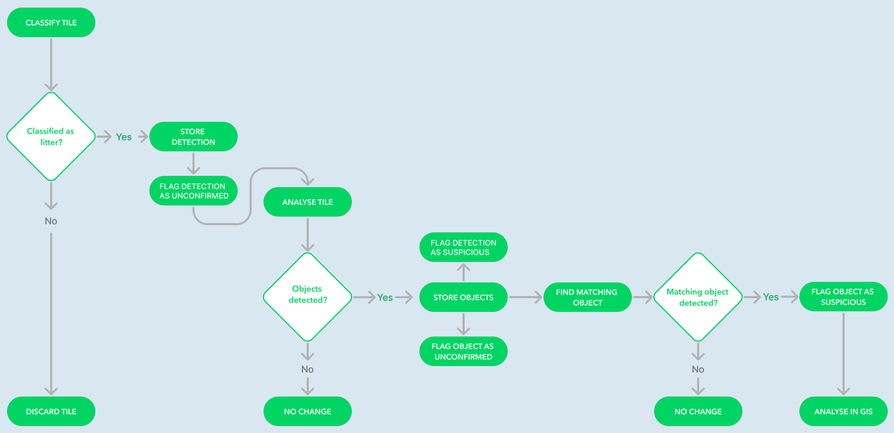


Figure 1. Classification, segmentation and tracking workflow

Methodology

A pre-trained convolutional neural network is fine-tuned with a hand-labeled dataset of objects floating on the sea surface extracted from Planet satellite imagery supplemented by synthetic training data, to learn the spatial and spectral characteristics of these objects. Our dataset consists of PlanetScope GEOTIFF images with 4 bands (RGB + NIR) and a size of 50×50 pixels.

Our software pipeline enables us to retrieve, process and classify large amounts of satellite images and allows continuous monitoring of selected areas of interest. As identifying floating objects in the marine environment by mere image classification is prone to uncertainties and complicated by cloud coverage, we further apply an image segmentation method (Figure 3). In order to increase the reliability of our prediction, we track objects on time series of satellite images with the help of an ocean current forecast model and a method that compares spatial and spectral characteristics of suspicious objects.

The Tiresias Forecasting System provided by CNR Ismar covers the Adriatic Sea and its northern lagoons and realises a seamless transition between different spatial scales adopting high spatial and temporal resolution of the forcing and boundary conditions. The system is able to forecast the general circulation features as well as coastal storm surge, sea water intrusion and particle dispersion. In our approach it forecasts potential object trajectories in 1-hour resolution.

Model	Train loss	Valid loss	Accuracy	Error Rate	Epochs (fine-tuning)
Resnet50	0.051394	0.066496	0.979948	0.020052	10
Densenet161	0.030701	0.171301	0.958152	0.041848	10
GoogleNet	0.231244	0.334864	0.894507	0.105493	20
XResnet50	0.169875	0.335455	0.888405	0.111595	20
VGG16	0.190660	0.393720	0.874455	0.125545	20
EfficientNet	0.420365	0.553654	0.815170	0.184830	20

Figure 2. Pre-trained model performance on training dataset

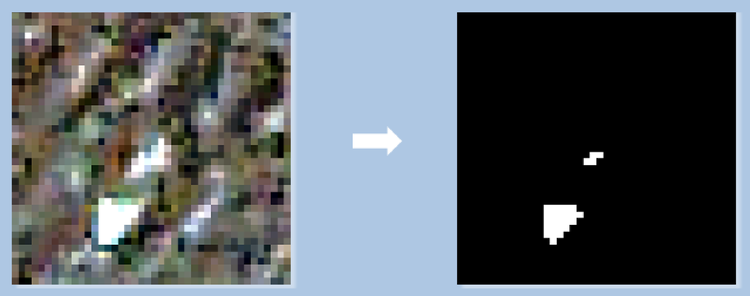
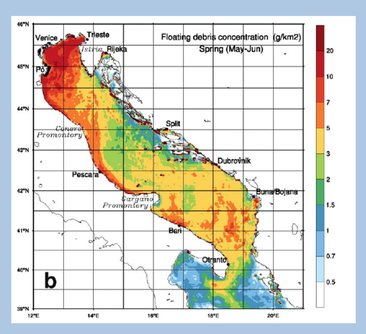


Figure 3. Object segmentation using iterative Otsu thresholding



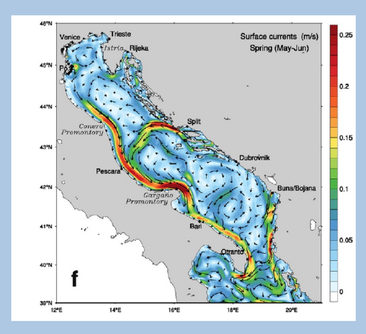


Figure 4. Floating debris concentration and surface currents in the Adriatic Sea during May and June

Results

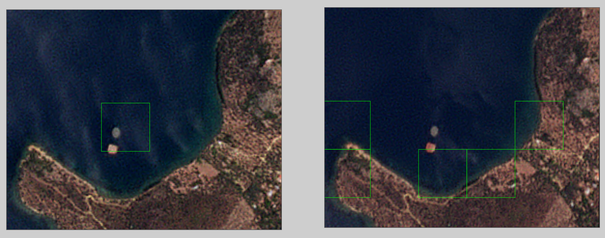


Figure 5. Model validation on ground truth data from Plastic Litter Project

Scenes	Tiles	Accuracy	Precision	Recall	F1 Score
23	460	0.96	0.63	0.52	0.56

Figure 6. Performance evaluation results

Figure 7. Time Series 1 (yellow): From May 28 to June 3, 2021, Time Series 2 (red): May 20 to May 26, 2021

The Resnet-50 network architecture showed the best performance in our comparison of different AI models for image classification fine-tuned with the same balanced dataset.

The real-world performance of the trained deep learning model in combination with the image segmentation was validated on 23 satellite images from Planet of artificial objects from the Plastic Litter Project. This project was initiated to calibrate remote sensing algorithms and validate their results by providing large targets deployed on the sea surface (Figure 9). The result of the validation is shown in Figure 6.

Furthermore, we tested the overall system on two time series in the Adriatic Sea from to May to June 2021 (Figure 7). The results were promising but still showed a high sensitivity of the image classification to sea bottom textures in shallow water, turbid sediments, white caps and small boats. Clouds similarly can cause false detections. We are addressing these issues by extending and improving our training features but the available spatial resolution of the multispectral satellite data of around 3m make small objects often not distinguishable for the human eye.

In order to allow stakeholders to dig into our monitoring data, identify hotspots, accumulation zones and litter sources, a web-based application (Figure 8) has been developed.

Conclusions

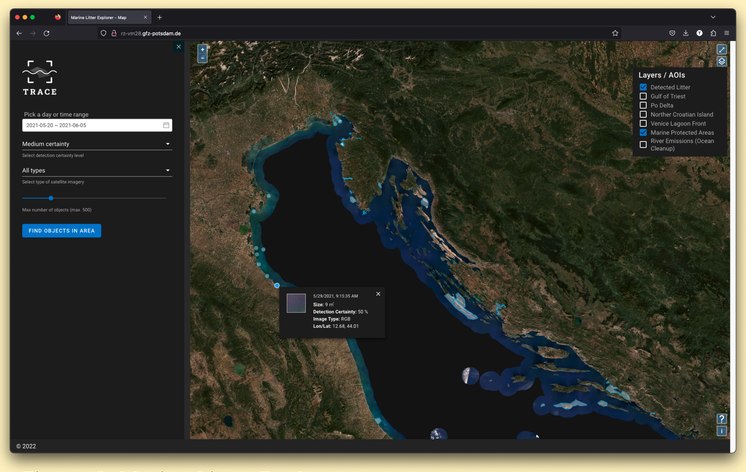


Figure 8. Marine Litter Explorer

Figure 9. HDPE mesh from the Plastic Litter Project in the Gera Gulf, Lesvos Island, Greece

Detecting marine debris from space is a challenging task, due to the ambiguous and diverse visual nature of litter, litter patches and accumulations. Data to train and fine-tune deep learning models is scarce, large efforts need to be invested in data engineering and domain exploration. Data diversity, regional variability as well as proper label differentiation is important.

Object tracking can help to increase the detection reliability but requires a regional ocean current model with a high temporal and spatial resolution as well as seasons of low cloud coverage. Due to missing GCP (ground control points) over water, the system also has to cope with a certain uncertainty in the geo-positions of the detected objects.

In the future, hyperspectral satellite data can help to improve the possibilities for material identification and distinction. Satellite missions, such as EnMAP, allow users to task hyperspectral satellite data acquisitions. We aim to enhance our detection method with an additional component that retrieves and analyzes hyperspectral data of areas for which the system has detected litter objects or accumulations.