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Campaign on Remote Sensing of Plastic Marine Litter

MUSS2: Multi-Model synthetic S2-HS (HyperSpectral) data for marine/plastic debris characterization

Executive Summary

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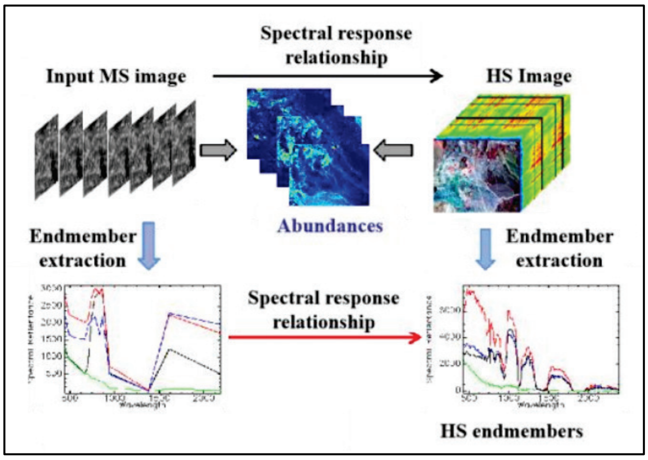
BACKGROUND AND GOALS

For plastic detection, characterization and tracking, we need rich spectral information, ideally hyperspectral (HS) data. Research based on full stretch (0.4 to 2.5 µm) HS for microplastic suggests Short Wave Infra-Red (SWIR) ranges are most useful in detecting debris >300 µm (Karlsson et al, 2016). In Garaba and Dierssen (2018), an airborne HS study of synthetic hydrocarbon detection using SWIR absorption features successfully identified debris from marine harvested macro- (>5mm) and microplastics (<5mm). Image analysis on 7.1 m pixel also identified band depth using 1702, 1732 and 1742 nm calibrated at-sensor radiance are most useful. In Driedger et al (2015), the authors suggested it is possible to detect common plastic debris in beach sand using Near Infra-Red (NIR) reflectance spectrometry at the range 890–2500 nm. In terms of spatial resolution for identification and tracking, Moy et al (2018) used HD aerial photo (30cm) to track debris. In summary, we would like ideally HS data up to SWIR (2500 nm) around 0.5 m Ground Sample Distance (and of course with a sufficiently high Signal-to-Noise- Ratio). Both of these characteristics are non-existent in current EO missions, and will still be difficult to find in future EO missions. To mitigate current challenges, we propose:

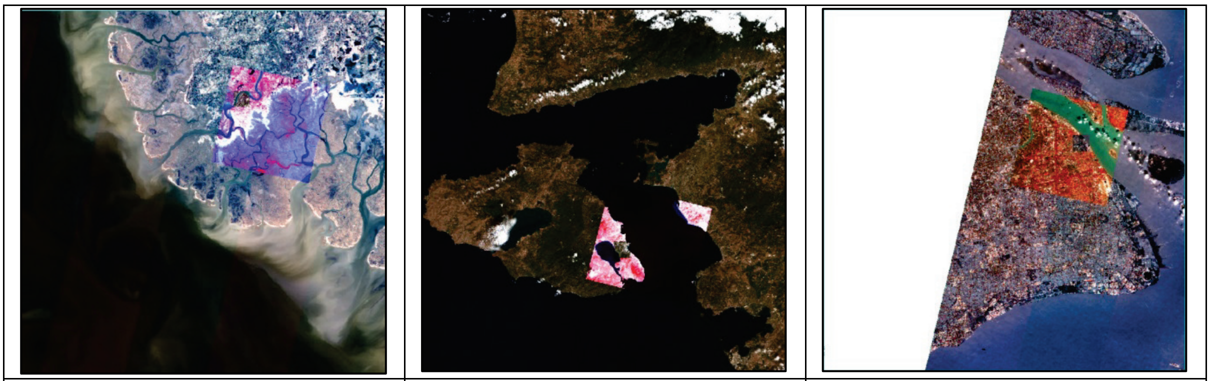
1) to use novel spectral enhancement method to generate simulated HS images from the Multi Spectral (MS) images of the Sentinel 2 (S2) Multi Spectral Instrument, by using dictionary learning and spectral response function modelling,
2) to investigate newly available PRISMA full stretch HS satellite images, and
3) to validate effectiveness of the synthetic S2-HS data for marine plastic identification via simulated mixed pixels with marine plastic,
4) finally, we reported results from spatial enhancement with HS-MS fusion using real targets.

THE RESEARCH

A. Spectral enhancement

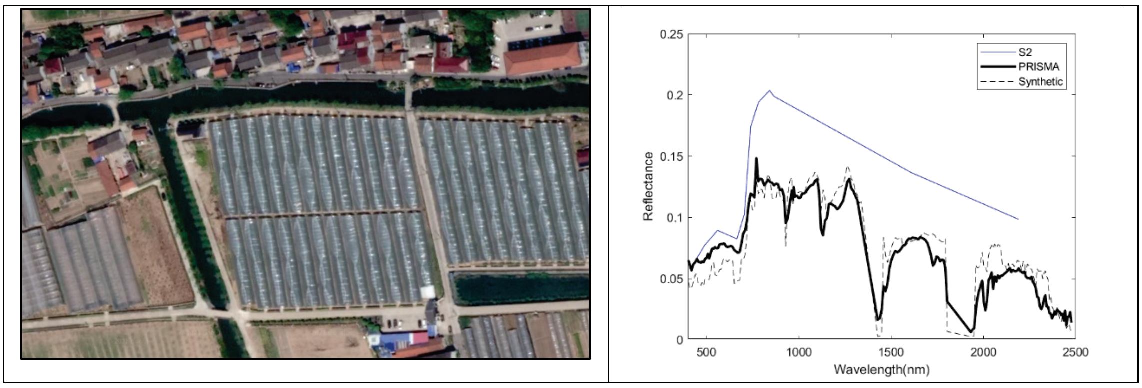


The Figure above shows the scheme of the enhancement methodology. Source: C. Yi, Y. Zhao, J. C.-W. Chan (2019) “Spectral super-resolution for multispectral image based on spectral improvement strategy and spatial preservation strategy”, IEEE Trans. on Geoscience and Remote Sensing 57 (11), 9010-9024.



a: Indus River	*b: Lesvos (Greece)*	*c: Shanghai*

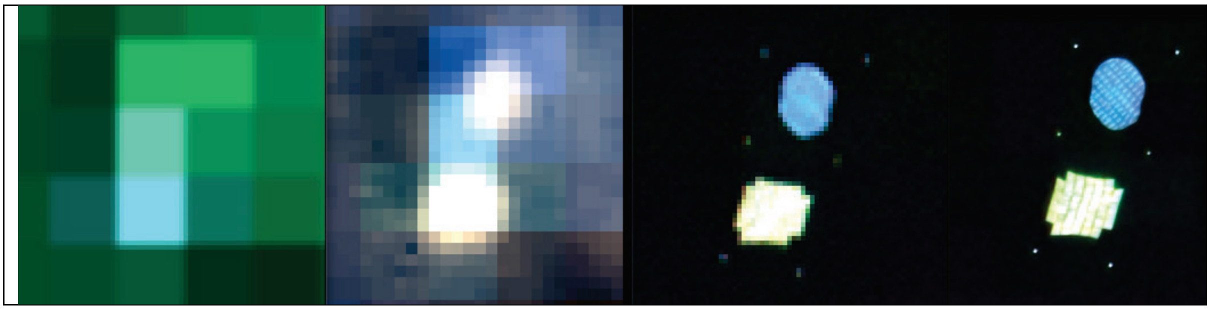
The Figure above shows the image pairs (S2 and PRISMA) for the sparsity-based method described in Yi et al. (2019).



The output is an image cube with PRISMA spectral configuration at 10m. The Figure above shows the comparison of the spectral signature of greenhouse extracted from (1) S2 in blue, (2) PRISMA in solid black line and (3) Synthetic HS image in dotted line.

B. Spatial enhancement

A fusion-based approach is adopted to increase the spatial resolution of PRISMA data. A WorldView 2 image is used as the high spatial resolution MS image to fuse with the low spatial resolution Hyperspectral PRISMA image. The result is a high spatial resolution HS image at the spatial resolution of the WorldView 2 images.



The Figure above shows the images of two floating plastic objects mounted for the PLP 2021 campaign[1] at different resolutions. From left to right: PRISMA (30m), Pansharpened PRISMA (5m), Fusion-based enhanced HS image at 2m and 0.5m.

[1] https://plp.aegean.gr/plastic-litter-project-2021

RESULT SUMMARY

1 Synthetic PRISMA-like HS images are successfully simulated from S2 MSI using sparsity-based enhancement method described in Yi et al. (2019). Implementation was first done with HYPERION-S2 training pairs, followed by PRISMA-S2 pairs.
2 Quantitative assessment suggests image quality of enhanced S2 images are satisfactory. Enhancement of S2 to PRISMA-like HS data has achieved good index performance (RMSE, CC, SAM, PSNR) due to the newer and more advanced sensor equipment.
3 PRISMA L2 images quality. In some scenes, we observe inconsistent calibrations between two spectrometers, VNIR and SWIR, leading to small discrepancy in two waveband regions. This however has not affected the results of the enhancement.
4 A small investigation to implement PANsharpening as a preprocessing step to see if overall performance can be improved. The PAN-sharpened PRISMA did not produce better HS simulation.
5 All experiments were conducted at L2 or ground level reflectance. The scenario of simulating TOA reflectance for preserving the absorption features at SWIR for plastic characterization have not been thoroughly investigated.
6 Open-source spectral library of marine plastic at material level and object level are downloaded. They are resampled to PRISMA spectral configuration for comparison.
7 A preliminary investigation to classification of greenhouse plastic roofs with the enhanced image has been made. Compared with the original PRISMA (30m) and S2 (10m), the synthetic HS data (10m) generated the highest Producer accuracy. In terms of User accuracy, it is comparable with S2 image. The synthetic data (10m) significantly outperformed the original PRISMA (30m). While its performance is close to S2, showing good potential for marine plastic/debris.
8 At present, we do not have enough data and particularly ground truth to positively identify useful spectral features at SWIR region (>1000nm) in PRISMA for characterization of plastic litter.
9 Evaluation with sub-pixel classification approach for the 10m synthetic HS data. Mixed pixels for a dozen of plastic-related classes are simulated at different fractions with seawater, and then injected randomly into the natural scene.
10 A simple linear unmixing mapping is performed and accuracy assessment was conducted. The results show consistent good detection rates for the majority of the investigated plastic-related classes mixed at different fractions. In general, higher accuracies are recorded for pixels with higher fractions of plastics.
11 Spatial enhancement has been implemented using PLP 2021 in-situ groundtruth objects at 3 different scenarios, Pansharpening with PRISMA Panchromatic band at 5m, Fusion with Worldview 2 (400-1000nm) at 2m, and at 0.5m.
12 Due to lack of groundtruth targets, the analysis on the potential of spatially enhanced images for marine plastics is very limited. While Pansharpening has avoided the need to find a HD multi-spectral image acquired at more or less the same time, and also avoided a possible challenging image co-registration, Pansharpening of PRISMA creates high variation in the end product partially due to the limited spectral info, as the Panchromatic band only covers the VIS wavelength. While the challenge of Fusion-based enhancement is to have a HD multi-spectral image acquired at the same time and also an accurate co-registration as a pre-requisite, the end-result is clarity in shape and texture of smaller objects.

RECOMMENDATIONS

High quality spectral enhancement for marine plastic could be further improved with TOA reflectance. This has not been investigated in this work due to time constraint, but should be studied in future works.

A major challenge for Marine Litter research with Earth Observation missions is lack of groundtruth data. And this has become the major challenge in this work. Without validated groundtruth, we are not able to verify the spectrally-enhanced S2 images for characterization of marine plastic. Innovative and coordinated field campaigns are urgently needed to fill the gap.

With the input of field campaigns, we will be able to understand the best waveband features for marine plastic. Such knowledge will enable us to design application-specific sensors for future spaceborne mission.