Enhancing PRISMA and Sentinel 2 Capabilities for Marine Plastic Litter Detection Using Image Fusion Techniques, Spectral Signature Unmixing and Spectral Indexes
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Abstract
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The challenge

Marine debris (MD), especially plastics, have been a severe worldwide concern for decades, having adverse environmental, socio-economic, maritime travel safety and marine life impact. Most recent research has been focused on detecting and monitoring floating debris through remote sensing data. Spectral characteristics have been analysed on both laboratory hyperspectral and satellite multispectral data in an effort to distinguish MD. Various classification methodologies as well as spectral indexes are the most common approaches for MD detection. However, restrictions on the spectral and spatial resolutions of the available sensors didn't allow for small plastic object detection. It is now clear that finer spatial and spectral resolutions would significantly improve the detection of MD accumulations. In this study, we exploit pansharpened PRISMA and Sentinel-2 (S2) fused with WV2/3 images for MD detection using spectral indexes and spectral signature unmixing.

Methodology

Experiments took place in Tsamakia beach and Geras gulf, Lesvos, Greece. Two PRISMA datasets (18/09/2020 and 22/10/2020) of panchromatic (5m) and hyperspectral PRISMA (30m) Top Of Atmosphere (TOA) radiance images and one dataset of S2 (20m) and WV3 (4m) TOA reflectance images (7/06/2018) are selected, depicting 12 artificial plastic targets of various materials (PET, LDPE, PS) and sizes (0.6x0.6 m2, 2.4x2.4 m2, 5.1x5.1 m2) are selected for the development of the methods. Each dataset (Fig. 1a,1b and 1g,1h) is accurately aligned, and noise is removed. Pre-processing and fusion are performed sequentially and then spectral signature unmixing (SSU) analysis and spectral indexes are applied on the produced data.

In the fusion step, fifteen pansharpening methods are evaluated on the PRISMA datasets, while two spectral unmixing-based and three deep learning fusion methods were evaluated on the S2-WV2/3 datasets for the best separability of artificial plastic targets and minimum image spatial and spectral distortions. Land and very swallow water pixels are then masked out in the pansharpened and fused images with the best performance.

For the MD detection, the SSU procedure is applied on both datasets, which can be summarised in the following steps: i) estimation of the number of endmembers (Outliers Detection Method (ODM)), ii) Dimensionality reduction (Minimum Noise Fraction (MNF)algorithm), iii) endmember extraction and labelling (N-FINDR, Spectral Angle Distance (SAD) algorithms), and iv) inversion of the fully constraint mixture model and calculation of the abundance maps (Network Based Method (NBM)).

Moreover, for the MD detection on the pansharpened PRISMA data, novel spectral indexes were developed and applied sequentially, based on radiance differences between spectrum crests and troughs in the VNIR region ($Index_1 = \frac{(R_{781}{}^2 - R_{951})}{1000}$, $Index_2 = \frac{(R_{596}{}^2 - R_{719}{}^2)}{10000}$, $Index_3 = R_{492} - R_{719}$), while SOTA spectral indexes (Floating Debris Index (FDI), S2-based index) were applied on the S2-WV2/3 fused data.

Results

The algorithms were evaluated on different datasets (two PRISMA, 23/06/2021 and 29/09/2021, and one S2-WV2, 29/06/2021). Pansharpened images (5m, 175 bands) were initially evaluated for their ability to discriminate the plastic targets from water using SAD and CC algorithms. The Principal Component Analysis (PCA) produces the least spectral and spatial distortions (Fig. 1c). For the S2-WV2/3 fused images (2-4m, 13 bands), the spatial and spectral distortions are minimized when the Coupled non-negative matrix factorization (CNMF) is employed (Fig. 1i).

Abundance maps produced by SSU for both groups of the datasets provided satisfactory separability between floating debris and water pixels (Fig. 1d,1e, 1j,1k,1l,1m). Abundance maps of endmembers labelled as plastic present high values for all plastic targets and very low values for water pixels, while the inverse occurs on abundance maps of water. It is noteworthy that for the S2-WV2/3 datasets, shallow water masking is not necessary and there are indications that separation among plastic materials is possible as endmember extraction provided spectra for each plastic material in the fused images and only one plastic endmember on the pansharpened images.

The detection of the plastic targets on pansharpened PRISMA images using the developed plastic indexes is quite accurate with only a few pixels most of them very close to the coast or remaining noise pixels, being erroneously indicated as plastic materials (Fig. 1f), while the FDI which exploits the S2 SWIR bands, was the only index that detected plastic debris in the fused images (Fig. 1).

Outlook for the future

Considering the hyperspectral datasets, some constraints arose in the unmixing analysis due to the spectral inseparability of the plastic targets and swallow waters. Considering the multispectral dataset (S2-WV2/3), the spectral unmixing analysis properly mapped the plastic and wooden targets. The high spatial and the medium spectral resolution provide satisfactory results when land is masked. Boats may be a problem for the detection of marine plastic litter as their spectral signature is almost identical with some plastic targets. By exploiting image fusion techniques, for a small plastic target to be distinguishable, it should at least occupy 8% of a pixel of the original hyperspectral PRISMA image or 3% of the original S2 multispectral image. Overall, the results of this study are very promising for the development of an automated algorithm for the detection of floating anthropogenic objects in marine environments. Though, more datasets are required for the algorithm tuning and adjustment.

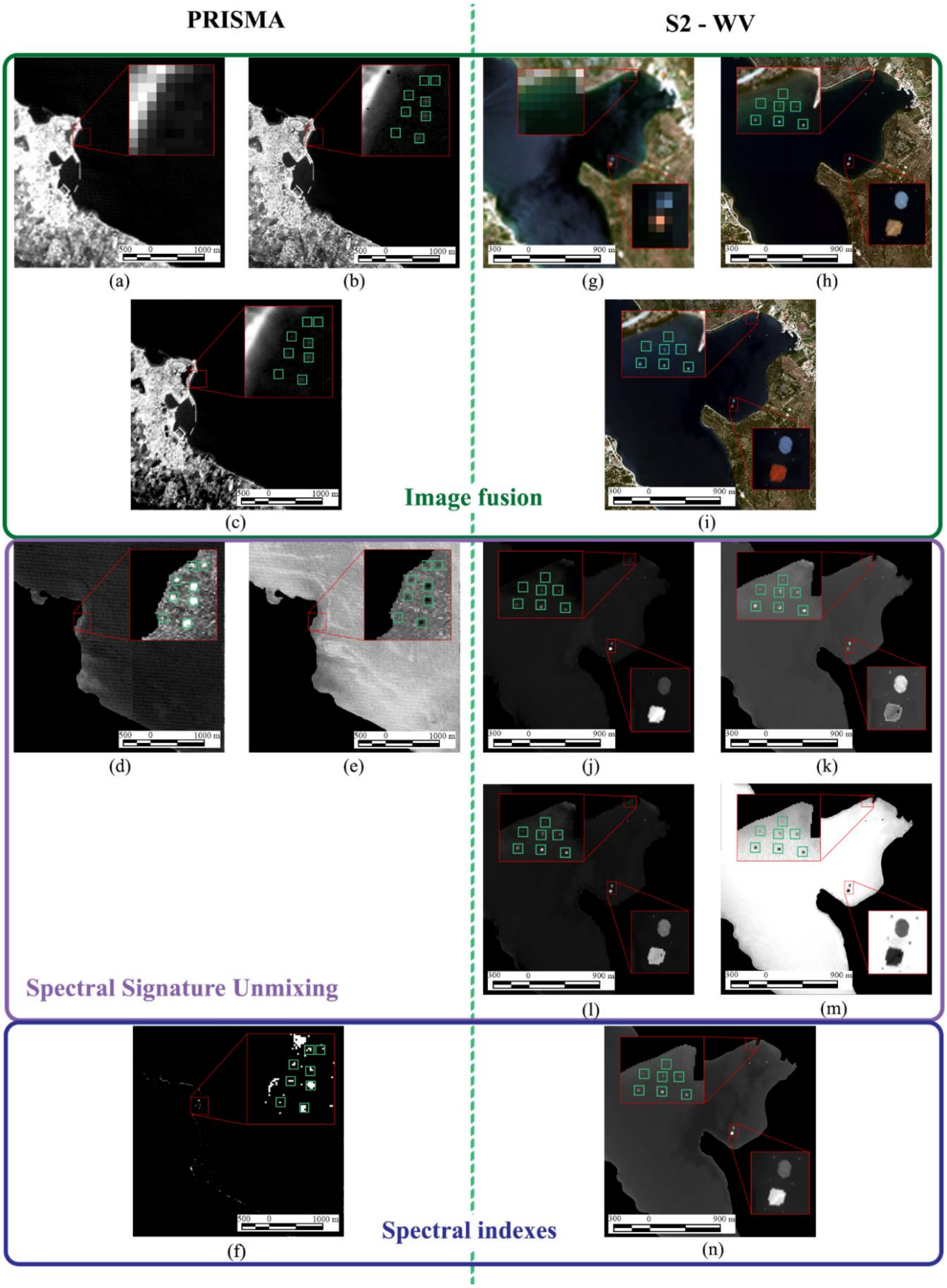

Figure 1 (a) Original PRISMA HS image (670nm). (b) Panchromatic image. (c) Pan-sharpened PCA image (670nm). (d) Abundance map of the endmember labelled as "plastic". (e) Abundance map of the endmember labelled as "water". (f) Mask produced by thresholding the developed spectral indexes on the PCA pan-sharpened image. (g) Natural colours RGB composite of S2 image with 10 m spatial resolution. (h) Natural colours RGB composite of WV-2 image with 2 m spatial resolution. (j-m) Abundance maps of the endmembers labelled as "wood", "mixed plastic", "Polystyrene" and "water" accordingly. (n) FDI application on the S2-WV-3 fused image. Red rectangles indicate the area where square plastic targets are located. Red boxes present a more detailed image of the targets while green boxes indicate the targets' location.