Real-time plastic litter detection and localization from drone for cleanup assistance

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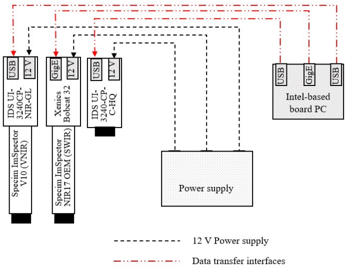
Abstract

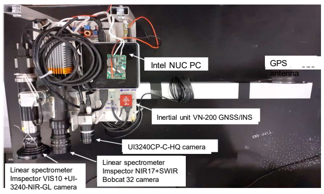
Plastic litter collection is a time-consuming and expensive task, and its cost is only marginally balanced by the value of recyclable materials, especially in open sea. Orienting the cleanup effort to areas where a significant amount of litter is located can significantly enhance the efficiency of such activity. When we tackle floating debris detection and collection, of course we must take into account that the material is continuously moving under the action of currents and wind, therefore aerial detection should not be aimed at static mapping, but rather used in direct synergy with collection systems to orient them, possibly in a fully automatic fashion, to the areas where a larger amount of waste is present. For this reason, the detection system must operate in real-time, and provide a flow of information continuously to monitoring stations and waste collection vessels.

Experimental setup

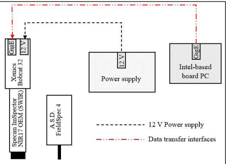
We assembled a stand-alone push-broom multi-purpose hyperspectral sensor system that contains a spectrometer device operating in the band 900-1700 nm (SWIR – short-wave infrared), with the purpose of realizing a stand-alone payload for a relatively small drone (a DJY Matrice 600).

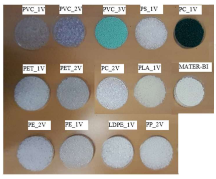
An Intel-based board PC performs data acquisition and storage, and data processing for detection and communication with a ground station. A compact INS provides Global Navigation Satellite System-based geolocation and attitude sensing, for hyperspectral cube construction and georeferentiation.

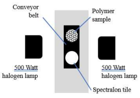




A preliminary investigation was carried out in controlled conditions (both in the laboratory and in the field, indoor and outdoor) to characterize plastic polymers







VIRGIN PLASTICS IN GRANULES			
NAME	**COLOR**	**DENSITY** (g/cm³)	**SIZE CLASS** (m)
PET_1V	White/transparent	1.30	$2.00\ 10^{-3} - 3.36\ 10^{-3}$
PET_2V	Transparent	1.31	$2.00\ 10^{-3} - 3.36\ 10^{-3}$
PVC_1V	Transparent	1.19	$2.00\ 10^{-3} - 3.36\ 10^{-3}$
PVC_2V	Transparent	1.30	$2.00\ 10^{-3} - 3.36\ 10^{-3}$
PVC_3V	Green	1.37	$3.36\ 10^{-3} - 4.76\ 10^{-3}$
LDPE_1V	White/Transparent	0.91	$3.36\ 10^{-3} - 4.76\ 10^{-3}$
PE_1V	Transparent	0.93	$3.36\ 10^{-3} - 4.76\ 10^{-3}$
PE_2V	White	0.92	$3.36\ 10^{-3} - 4.76\ 10^{-3}$
PP_2V	White	0.91	$2.00\ 10^{-3} - 3.36\ 10^{-3}$
PC_1V	Green	1.18	$2.00\ 10^{-3} - 3.36\ 10^{-3}$
PC_2V	Transparent	1.17	$3.36\ 10^{-3} - 4.76\ 10^{-3}$
PS_1V	White/Transparent	1.04	$3.36\ 10^{-3} - 4.76\ 10^{-3}$
PLA_1V	Transparent	1.24	$3.36\ 10^{-3} - 4.76\ 10^{-3}$
MATERBI	White	1.25	$3.36\ 10^{-3} - 4.76\ 10^{-3}$

Methodology for data analysis

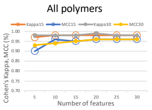
Our detection methodology is based on linear classifiers, obtained by Linear Discriminant Analysis applied on a subset of spectral bands selected by the minimum-redundancy- maximum-relevance algorithm. The 10 nm bands automatically chosen by this algorithm are mostly located between 1180 and 1270 nm and between 1510 and 1620 nm. The classifier is obtained by optimization on a wide set of manually labeled examples taken from data gathered in various sites and environmental conditions. For waste collection assistance purposes, we need to process the data in real-time on-board the drone, and send detection results to a ground station by radio-link. In this case, we do not need high spatial resolution, and even the localization accuracy is not so strict, so that we may process each hyperspectral image (that has a footprint on the surface of several meters across the flight trajectory) at once, giving a single detection response, and associate a relatively rough geo-localization by reading the GNNS position of the drone simultaneously with each image acquisition. The message is received by radio link at the ground station, a computer running a real-time mapping thread that frequently refreshes a map where yellow or red dots are plotted according to the plastics indicator. Of course, the same data flow can be directly forwarded to a waste-collection system.

Results

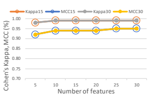
The performance of the classification algorithms (LDA and K-NN) tested as a function of the number of training spectral signatures (15 and 30 for each 'object' to recognize), number of features extracted from the training signatures (5-10-15-20-25-30) and number of components (from 1 to 5) for the learning algorithms mRMR and PCA respectively. Two strategies for classifying the plastic polymers were considered: 1. Classification of any plastic sample within the hyperspectral cube under investigation; 2. Classification of each plastic sample as an item, i.e., recognition of PE and PET. The performance of the classification machine learning model for the different plastic typologies was evaluated by using the concepts of True Positive Rate (TPR), False Negative Rate (FNR), True Negative Rate (TNR), and False Positive Rate (FPR), Cohen's Kappa and Matthews Correlation Coefficient (MCC).

The algorithm combinations LDA/mRNR and LDA/PCA perform better with 15 training signatures, 20 features for mRNR and 4 components for PCA.

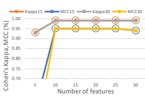
All polymers

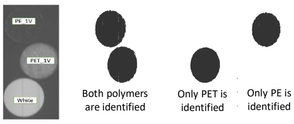


PET



PE



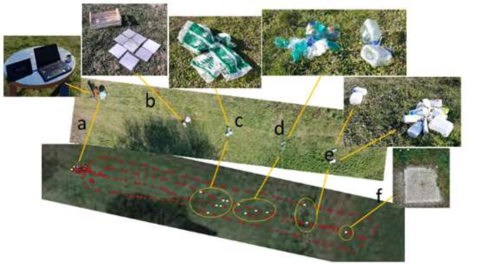


Both polymers are identified

Only PET is identified

Only PE is identified

We tested the system in controlled ground environments where we put some plastic litter on purpose, and on some river and beach sites (both in water and on the shore), obtaining reliable detection even of single objects, such as bottles or pieces of boxes.



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