Hyperspectral Remote Sensing of Marine Plastics (HYPER)

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ABSTRACT

Hyperspectral reflectance datasets on marine plastic litter are scarce. They are however essential to build robust algorithms to identify and characterise marine plastic litter. The HYPER project has resulted in a hyperspectral reflectance database of 47 marine litter samples. The project has also analysed the spectral database to provide information on the most suitable wavelengths for marine plastic identification. These take into account the spectral properties of the marine litter, but also the spectral properties of surface features such as white caps and the spectral properties of sediment plumes. This is essential to exclude false positives in the detection of the marine litter.

Keywords: Hyperspectral, marine plastics, litter

1. INTRODUCTION

The HYPER project developed a reflectance database of marine plastic litter and identified the most important spectral bands needed to identify marine litter from remote observations.

Remote observations of marine litter allow to have a better view on the marine litter problem and to evaluate action plans taken to reduce the amount of plastic litter in our rivers and oceans. It is estimated that more than 150 million tonnes of plastics have accumulated in the world's oceans, while 4.6-12.7 million tonnes are added every year (Jambeck et.al, 2015). The well-known properties of plastics such as the durability and strength have increased its consumption drastically but have also made it a serious environmental problem. The plastics degrade very slowly and stay in the ocean for years. They have negative impacts on the marine biodiversity and human health.
To be able to act, one should have a better view on the actual problem and have standardised methods to follow up implemented measures. Remote observations, either from satellite, drones or fixed cameras have the potential to identify plastic litter in a standardised way. Satellites can cover large accumulation zones and their changes, whereas drones and fixed cameras can monitor hotspot areas, identify single plastics and discriminate the plastics from other litter such as wood.

Although much knowledge is available on the spectral properties of plastics, mainly from industrial sorting, this information cannot simply be used to develop a monitoring system based on remote sensing. The remote sensing of marine litter in an outdoor marine environment has to deal with many issues that do not play a role in an indoor industrial setting. For instance, simply using the Short Wave InfraRed (SWIR) absorption features to discriminate between polymer types will not work when plastics are wet and the water absorbs all reflectance in the SWIR.
By establishing a database of marine litter, collected in an environment simulating real marine conditions, the HYPER project allows to draw conclusions on the wavelengths needed and types of cameras to be used. The marine conditions were simulated in a tank at Flanders Hydraulics. The tank was covered by black cloth and lamps were used to generate homogeneous lightning conditions. Different plastics were used and submerged in the water of the tank. Sediments from the Deurganckdock in Antwerp (Belgium) were added in different concentrations and kept in suspension.

The spectral database has been compiled and will be published in an open access repository. Two scientific publications are in preparation for peer review. Here we summarize the main results of the project.

2. STATE OF THE ART

Type of plastics

The vast majority of plastics are derived from fossil hydrocarbons and they can be categorized according to their polymeric composition (e.g. Polyethylene Terephthalate - PETE or PET- such as drinking bottles, High-Density Polyethylene – HDPE - such as water bottle caps and milk bottles).

Plastics are also being categorized in terms of size. First, there are the large macroplastics which are visible by the human eye such as drinking bottles, plastic bags and ropes. Then, there are the smaller microplastics which can originate from the large, visible pieces by degradation into smaller fragments (Van Cauwenberghe, 2013). Apart from the degradation of macroplastics, microplastics are also being manufactured and used in e.g. cosmetics (Fendall and Sewell, 2009). Many authors have defined microplastics as particles smaller than 5 mm (e.g. Arthur et al., 2009).

Spectral properties of plastics

The waste management and recycling industry has been at the forefront of sensor development, they have robust tailor-made sensors that automatically classify plastic by polymer type, colour and even shapes (Huth-Fehre et al., 1995; Masoumi et al., 2012; Moroni et al., 2015; Wienke et al., 1995). The chemical composition of the plastic polymers is derived from the spectral measurements in the SWIR (1000 – 2500 nm) to MIR (2500 – 5000 nm) spectrum (Miller and Willis, 1956; Vázquez-Guardado et al., 2015).

For example, already in 1995, D. M. Scott proposed a method for the identification and separation of PET and PVC based on the absorbance peak occurred at 1660 nm for PET and at 1716 nm for PVC. Masoumi et al., (2012) used two similar spectral bands (1656 and 1724 nm) related to PET and HDPE spectral peak points and used their ratio to discriminate between PET, PS, PVC, PP and HDPE. Many authors (e.g. Vazquez-Guardado et al., 2015 and Masoumi et al., 2012) also showed that black plastics have very weak reflectance almost buried into the noise level.

In an outdoor marine environment, plastics can be wet, slightly or fully submerged. Think about a plastic bag that is floating in a river and partially dragged down by the current. In dynamic rivers and coastal waters, there are also surface features such as glint and white caps on the surface, there can be plumes of suspended sediments and blooms of phytoplankton. All these might complicate the identification of the plastic litter. Few researchers have started to derive spectral properties of harvested marine plastics and wet plastics (Garaba and Dierssen, 2018; Garaba and Dierssen, 2020) and have started developing algorithms to identify plastics from remote observations (e.g. Biermann et al., 2020). However, because of the large diversity of plastics, in composition, colour, size, there is a need to better characterize the plastics in the outdoor marine environment and build more robust algorithms.

3. BREAKTHROUGH CHARACTER OF THE PROJECT

The project can provide a new way of marine macroplastics monitoring. Overall, the current methods such as sightings and the use of plankton nets are not sufficient to provide a good view on the marine plastics distribution. Remote sensing allows to provide standardized, objective measurements, cover large areas at relatively low operational cost.

A better view on the spectral reflectance of marine plastics, allows to build reliable and robust algorithms for plastic identification in a real marine outdoor environment. Further, it allows the industry to build a dedicated marine plastics sensor. Existing sensors used in plastic sorting are not designed for this outdoor environment, nor to be mounted on e.g. a drone platform.

4. PROJECT RESULTS

The results of the project are currently being complied in a scientific publication and the spectral reflectance dataset of all acquired plastic litter will soon be published in an open access database. Some of the results are presented below.

Figure 1 shows the spectral reflectance of different Polypropylene (PP) ropes (orange, blue and white), measured in the VITO calibration facility in dry conditions. The white and blue rope were measured in compact and non compact conditions as illustrated in Figure 2. Absorption features can be observed in the SWIR region, corresponding to the ones identified in the literature. Large variability in the visible wavelength range can be seen, linked to the apparent colour of the ropes. Compactness of the rope influences the magnitude of the spectral reflectance.

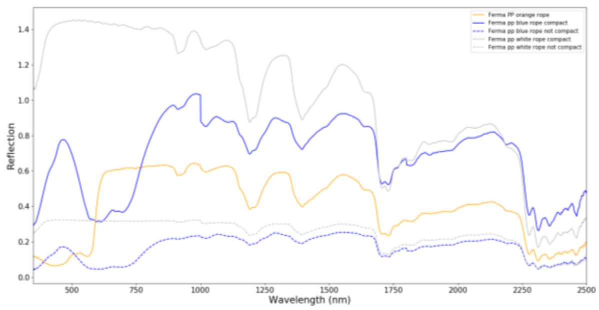

Fig.1: Spectral reflectance of different PP ropes

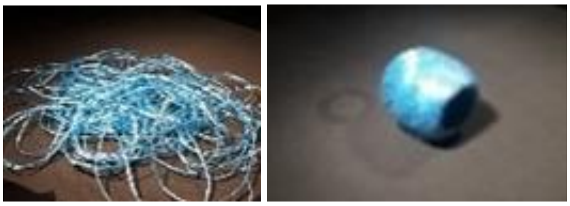

Fig.2: Blue rope, not compact and compact condition

Figure 3 shows the white rope, in dry and wet conditions collected in the tank at Flanders Hydraulics. Wettening of the plastics mainly influences the reflectance spectrum at longer wavelengths (beyond 800nm). Here, the wet reflectance is lower compared to the reflectance of dry sample because of the strong absorption of the pure water.

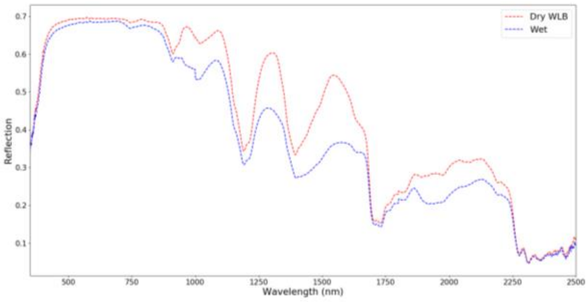

Fig.3: White rope, wet and dry condition

Finally, Figure 4 shows the reflectance of a yellow placemat when submerged in the water tank. Clearly, submersion has an enormous implication for detection of plastics in the SWIR. Even with a slight submersion of 2 cm, no reflectance signal is measured beyond 1148 nm (reflectance threshold of 0.01). Also the Near Infrared (NIR) reflectance changes and the shape resembles the shape of the pure water absorption. This means that submerged plastics will only be detectable in the visible wavelength range.

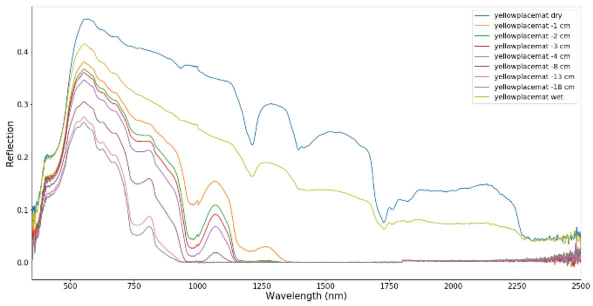

Fig.4: Yellow placemat

Further effects of surface features such as white caps were evaluated and complicate the identification of plastics in the visible and NIR wavelength range. Therefore, a combination of the right wavelengths in the VIS, SWIR and information on the shape of the plastics will provide a solution for plastic detection and discrimination of plastics from surface features.

5. FUTURE PROJECT VISION

5.1. Technology Scaling

The HYPER project has performed the experiments in a controlled laboratory environment, simulating real marine conditions (TRL 3-4). Testing should now be done in an outdoor environment including natural lightning conditions, taking into account surface features such as glint and white caps on the water surface and taking into account a variety of atmospheric conditions. This will allow to scale up the technology to TRL 5-6.

Testing in an outdoor environment will also require a different camera setup than the one used in the HYPER project. This new camera setup requires to expand the current consortium.

Finally, results have highlighted the need to combine spectral information with information on the shape of the plastic litter. Therefore, an A.I. network needs to be trained properly to take into account the large variety of plastic litter and different atmospheric conditions.

5.2. Project Synergies and Outreach

The existing consortium should be reinforced with a camera manufacture and potentially a company for clean-up activities.

Outreach will be achieved by the 2 scientific publications and the open access spectral database. Further, a blog has been published on the VITO remote sensing website (https://blog.vito.be/remotesensing/detecting-marine-plastics) which already attracted the attention of scientist and the industry. A new blog will be published when final results are published.

5.3. Technology application and demonstration cases

The developed technology can be used to

1) Reduce the amount of waterway litter entering the open ocean. By capturing the litter in the waterway it does not reach the open ocean where it is much harder to track and trace. Further, by collecting macro-litter, in a an early stage, it does not turn into microplastics which disappear into the ocean. In this case the litter detection system could be installed on a bridge, a fixed pole along the shore and linked to clean up activities.

2) Provide a better view on plastic accumulation zones, the size of the zones, the percentage of litter compared to the total litter and the seasonal fluctuations.

Both allow to get a better view on the amount and types of litter passing by. Tracing the litter allows to evaluate measures taken and re-align policy plans and regulations if needed.

5.4. Technology commercialization

No concrete steps for commercialization have been taken so far. An upscaling to higher TRL/ demonstration in real outdoor environment is needed first.

The future steps towards commercialization include:

- Next to technical feasibility, include more in depth analysis of economic viability including cost benefit analysis.
- Set-up collaboration with optical instrument manufacturer.
- Proof-of-Concept demonstrations for potential customers to raise interest.

5.5. Envisioned risks

Failure to work in outdoor conditions. This might be a risk because the tests have only been performed in the laboratory so far. To mitigate this risk, the algorithm may include information on the shape and size of the plastic litter next to spectral information.

In an outdoor demonstration, an imaging camera needs to be used but this camera might not fulfil the requirements. These cameras have not been used for this purpose before and, in the laboratory, spectral measurements were only collected with the point spectrometer (ASD). Mitigation includes the use of different types of cameras from different manufacturers and different installation options (bridge, pole, drone etc…).

5.6. Liaison with Student Teams and Socio-Economic Study

Liaison with students and also the general public will allow to raise awareness of the plastic litter problem. Students and the general public could play an important role in the project and help in the construction of the A.I. plastic litter database. Such a database can be used for training of the A.I. algorithm. Students can help by taking picture of marine/waterway litter and identify the type of litter (bag, bottle rope, colour, size...).

The project will also link with national and international activities on plastic pollution. For instance, crowd sourcing initiatives on plastic litter already take place and are organized by local governments.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] Arthur, C., Baker, J., Bamford, H., 2009. In: Proceedings of the International Research Workshop on the occurrence, Effects and Fate of Microplastic Marine Debris. NOAA Technical, Memorandum NOS-OR&R-30, p. 49.

[2] Biermann, L., Clewley, D., Martinez-Vicente, V., Topouzelis, K., 2020. Finding Plastic Patches in Coastal Waters using Optical Satellite Data. Sci Rep **10,** 5364

[3] Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: microplastics in facial cleansers. Mar. Pollut. Bull. 58: pp 1225–1228.

[4] Garaba, S. P., and Dierssen, H. M., 2018. An airborne remote sensing case study of synthetic hydrocarbon detection using short wave infrared absorption features identified from marine-harvested macro- and microplastics. Remote Sensing of Environment, 205: pp. 224-235.

[5] Garaba, S. P., and Dierssen, H. M., 2020. Hyperspectral ultraviolet to shortwave infrared characteristics of marine-harvested, washed-ashore and virgin plastics. Earth System Science Data, 12(1): pp. 77-86.

[6] Huth-Fehre, T., Feldhoff, R., Kantimm, T., Quick, L., Winter, F., Cammann, K., van den Broek, W., Wienke, D., Melssen, W., and Buydens, L. (1995) NIR - Remote sensing and artificial neural networks for rapid identification of post consumer plastics. Journal of Molecular Structure, 348 (0), pp. 143-146.

[7] Jambeck, J. R., R. Geyer, C. Wilcox, T. R. Siegler, M. Perryman, A. Andrady, R. Narayan, K. Lavender Law, 2015. Plastic waste inputs from land into the ocean. Marine pollution, 347(6223): pp 768-771.

[8] Masoumi, H., Safavi, S. M., and Khani, Z., 2012. Identification and classification of plastic resins using near infrared reflectance spectroscopy. World Academy of Science, Engineering and Technology, 6, pp. 141-148.

[9] Miller, R. G. J., and Willis, H. A., 1956. Quantitative analysis in the 2-μ, region applied to synthetic polymers. Journal of Applied Chemistry, 6 (9): pp. 385-391.

[10] Moroni, M., Mei, A., Leonardi, A., Lupo, E., and Marca, F, 2015. PET and PVC separation with hyperspectral imagery. Sensors, 15(1): pp. 2205.

[11] Scott, D.M., 1995. A two-color near-infrared sensor for sorting recycled plastic waste. Measurement Science and Technology, 6: pp. 156-159.

[12] Van Cauwenberghe, L., M. Claessens, Vandegehuchte, M.B., Mees, J., Janssen, C.R., 2013. Assessment of marine debris on the Belgian Continental Shelf. Marine Pollution Bulletin, 73: pp 161–169.

[13] Vázquez-Guardado, A., Money, M., McKinney, N., and Chanda, D., 2015. Multi-spectral infrared spectroscopy for robust plastic identification. Applied Optics, 54(24): p. 7396-7405.

[13] Wienke, D., van den Broek, W., and Buydens, L., 1995. Identification of plastics among nonplastics in mixed waste by remote sensing near-infrared imaging spectroscopy. 2. Multivariate image rank analysis for rapid classification. Analytical Chemistry, 67(20): pp. 3760-3766.