Identification of Plastics using Infrared Hyperspectral Imaging & Raman Spectroscopy

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Problem

Plastic and subsequently microplastic are currently present at the highest and lowest points on the planet. This promptly calls for an in-situ detection method to be developed. Yet, today there are few well functioning commercial solutions to in situ plastic recognition.

The resilient nature of plastic makes it persist and introduce toxins in the food chain. In turn, due to bio accumulation, it may cause severe ripples, endangering species throughout the food chain. The same characteristic makes the particles distinguishable from natural occurring particles, opening the possibility for detection.

Introduction

The work completed in this thesis acts as a stepping stone towards forming an underwater sensor for plastic detection. Laboratory experiments have been completed using separate methods such as Infrared Hyperspectral Imaging and Raman spectroscopy. Both technologies are demonstrated satisfactory for land-based object detection, including microplastics. Operating the sensors beneath the surface, however, carries additional challenges and hence consideration. The objective of this master thesis is, consequently, to investigate whether we can **build a model capable of recognizing marine microplastics underwater**, using the previously mentioned technologies.

Concepts

Spectroscopy is an imaging technique which records a high number of wavelengths, in contrast to regular imaging which records RGB(Red, Green, and Blue). Hundreds of spectral bands in a wide range may be recorded yielding a spectral signature. This may detect subtle differences, uncovering unique characteristics useful for classification purposes. The types of spectroscopy used in this study are Near-Infrared Hyperspectral imaging and Raman spectroscopy. Both are able to detect different chemical compositions based on the interaction between incident light and covalent bonds. These methods are usually used in the field of analytical chemistry due to their non-invasive nature. The acquired data was processed using different classification algorithms aimed at handling large amounts of data.

Conclusion

The results suggest that the predictions, and hence the models, manage to classify plastics independent on size, color and environment. Of the pieces collected in situ, from Lofoten, six piece are classified as plastic (PP and PE). However, as the nature of these samples are unknown, the resulting classification cannot be verified.

References

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[3] Yutaka Kaburagi, Akira Yoshida, Yoshihiro Hishiyama: *Materials Science and Engineering of Carbon, Chapter 7 - Raman Spectroscopy*, 2016

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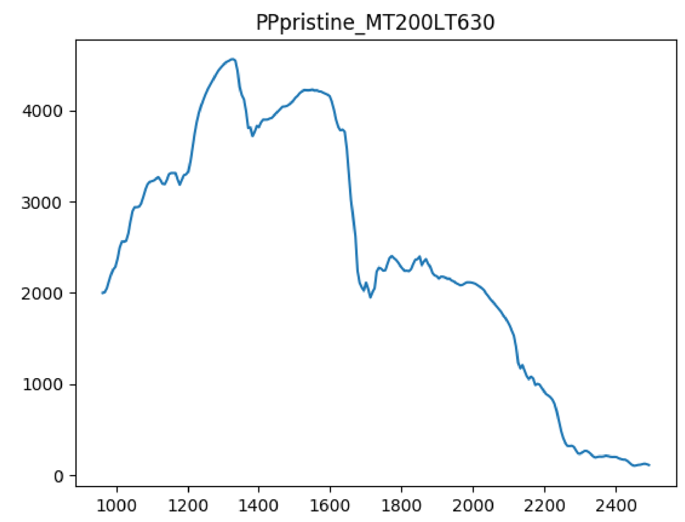
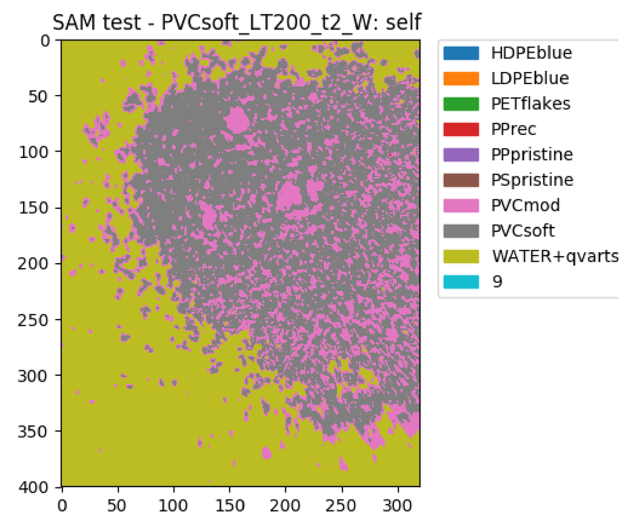
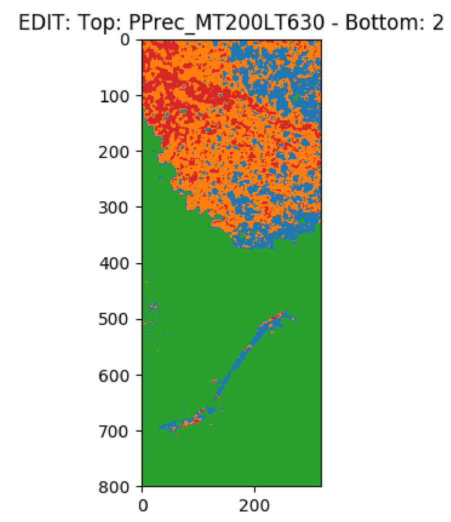
Infrared Hyperspectral Imager - Method and Results

The wavelengths of infrared radiation correspond to the vibrational frequencies of organic bonds. This means that whenever a plastic molecule is exposed to infrared radiation, the organic bonds in the plastic sample will absorb the radiation energy and excite to a higher vibrational energy state. These specific molecular changes are detectable by the hyperspectral imager (Hyspex SWIR 320-e [2]), allowing the imager to identify the corresponding molecules of the sample [1].

To exploit these characteristics, laboratory (A073, Electrical Engineering Building at NTNU Gløshaugen) was set with near-infrared light sources transmitting through the sample on its way to reaching the imager. 67 samples were imaged in the interval, 960 to 1240 nm. Furthermore, the images were analyzed using a clustering algorithm called K-means clustering with eight or twelve clusters, ten iterations and a relative tolerance for convergence at $1e^{-4}$. Moreover, a Spectral Angle Mapper algorithm was used to classify the clustered data, supervising the unsupervised clustering. The endmember signatures used in the SAM algorithms gather in the lab, rather than using an external library. The following illustrations show the spectral signature of pristine Polypropylene in the size range 630 to 200 micron, the identification of PVC in water using a combination of spectral angle mapping and K-means clustering, and the use of K-means clustering on a concatenated image of a known plastic type and a live sample from Lofoten. In the final image, the top sample is used for ground truthing. By knowing the type of plastic of the top clusters one gains an indication of the unknown sample below.



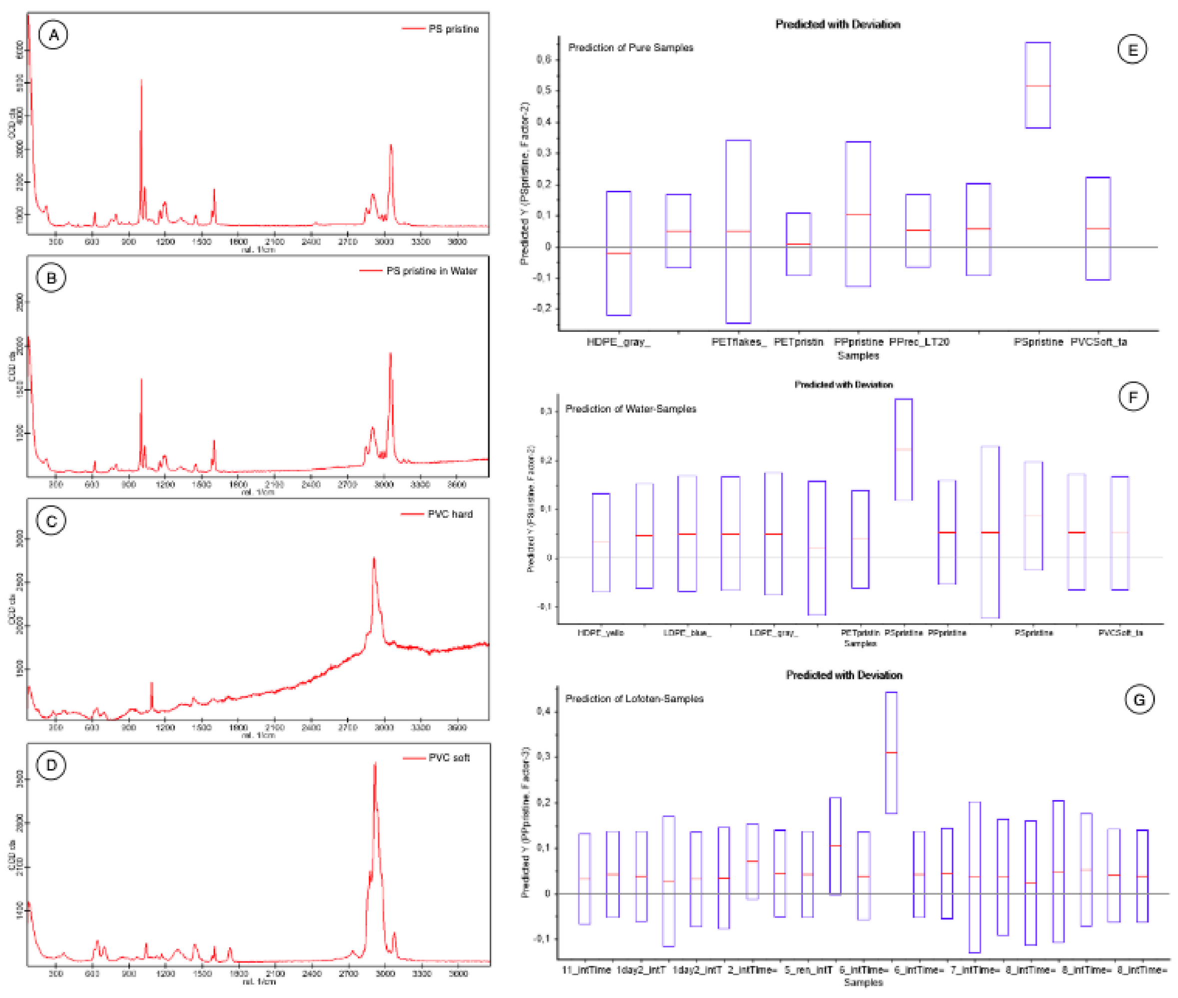




Raman Spectroscopy - Method and Results

Whenever a sample is exposed to light (in this case a laser at 523 nm), a small portion of the light is scattered by the sample. A minor part of this light holds a frequency different to that of the incident rays. This is called Raman scattering. The change in intensity caused by the energy (frequency) difference is distinguishable by the spectrometer, which, in turn, can identify properties revealing object composition from the spectral signatures of the illuminated sample [3]. After imaging the samples in Laboratory EU2-115, NTNU Gløshaugen, the data was analyzed using Unscrambler X. Using the software, a PLS-DA model was built to predict test-sets from plastic in water-samples and unknown sea-influenced samples. The model used every measured wavelength as a variable and thus were also able to predict more significant intervals of the signatures.

The figure to the left displays a representative number of resulting plots from the analysis performed. The left column, A-D, presents respective Raman signatures for single samplings, while the right column, E-G, shows prediction plots.



Sub-plot E indicates that the model manages to predict PS pristine as PS pristine. This result is representative for six out of the nine types of plastic measured. The corresponding spectral signature is presented in plot A. Plot B is the signature from the same type of plastic but in water. Comparing A and B, the trend is that the intensities are significantly lower when the laser has to penetrate water to reach the sample. However, the water does not seem to affect the distinguishable peaks. Similar, plot F, describing the prediction of PS pristine in water, communicates that the model indeed handles plastics in water as well. This result describes five of the six types measured. Plot C and D display the signature of PVC hard and PVC soft, respectively. The peaks in the plots indicate similarities in the material. Still, the model did not manage to classify them both as PVC, merely as distinct types. Plot G presents the prediction of the microorganisms collected from the sea outside Lofoten. One sample is classified as PP pristine.

Collecting Plastic Particles in Lofoten