# Hyperspectral Imaging for Overlapping Polymer Flakes Segmentation

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Winter 2022

## Introduction

- UNEP reports that as of 2015, only 9% of generated plastics had been recycled. [1]
- NIR Hyperspectral Imaging is commonly used to polymer segmentation.
- Polymer overlaps in the conveyor belt might lead to errors in the segmentation.
- Overlap data is costly to obtain due to number of variations and difficulty to annotate with precision.
- Bitfield encoding could help solve the polymer overlaps problem because allows models to be trained with only primary classes.

## Materials and Methods

- We use a Specim FX17 NIR camera to capture the images, see Fig. 1.
- Three preprocessing steps: Flat-field Correction, Z-Score, Spectral Normalization.
- We present bitfield encoding, an approach that allow models to be trained without overlaps but can predict them.
- U-net [2] as base architecture (see Fig 4), adapted to 224 bands hyperspectral images.
- Two datasets created for this task that contain images with polymer overlaps: Overlaps Dataset (OD) of 11 images, Controlled Overlaps Dataset (COD) 33 images.

## Abstract

Plastic recycling is crucial to reducing the environmental footprint. In this research, we use two hyperspectral datasets to segment with U-net in the context of plastic recycling. We segment three polymer types: PP, PE, PET and their overlapping combinations. We present bitfield encoding - a new multi-label encoding approach - and we use it for the polymer flakes overlaps problem, where some classes are a combination of primary ones. We trained U-net with bitfield encoding with overlaps, achieving the same performance as a standard approach. Moreover we trained U-net with bitfield encoding and only primary classes and tried to predict overlaps, obtaining results that help achieve that goal in the future.

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**Figure 1.** Specim FX17 NIR(900-1700nm) Hyperspectral line-scan camera. Can take line images of 1x640 pixels 224 bands each.

## Materials and Methods

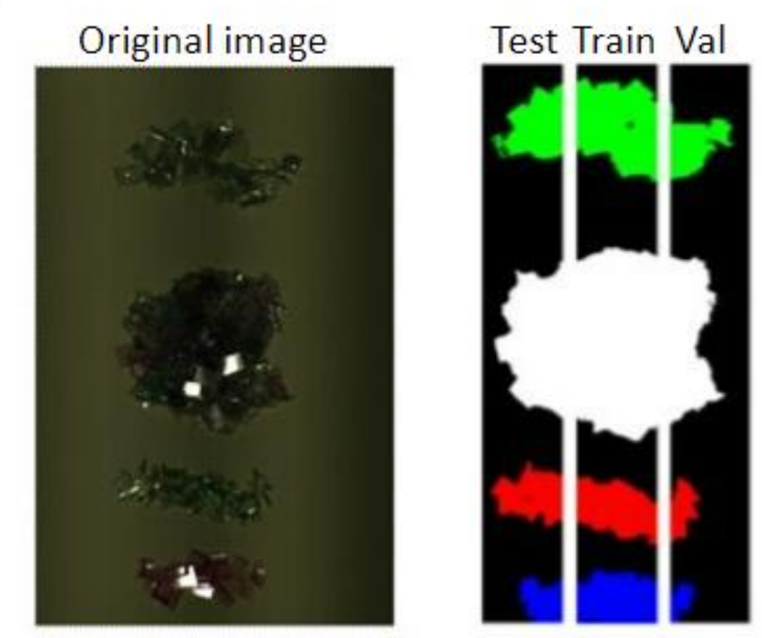


**Figure 2.** OD dataset creation example. To the left, a preview of an image. To the right, the ground truth sliced in three. The slices go to test, train and validation respectively.

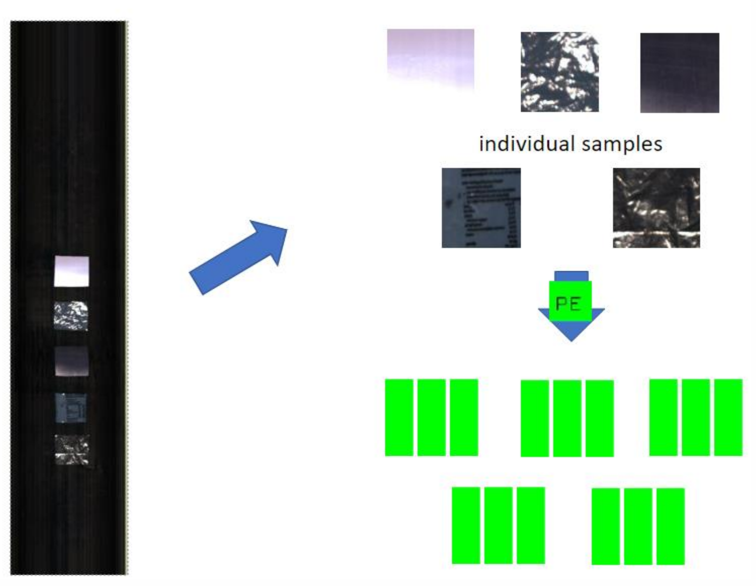


**Figure 3.** COD dataset creation example. To the left, a preview of an image. The original image is centered and cropped in the different samples and further divided in three slices that go to test, train and validation respectively.

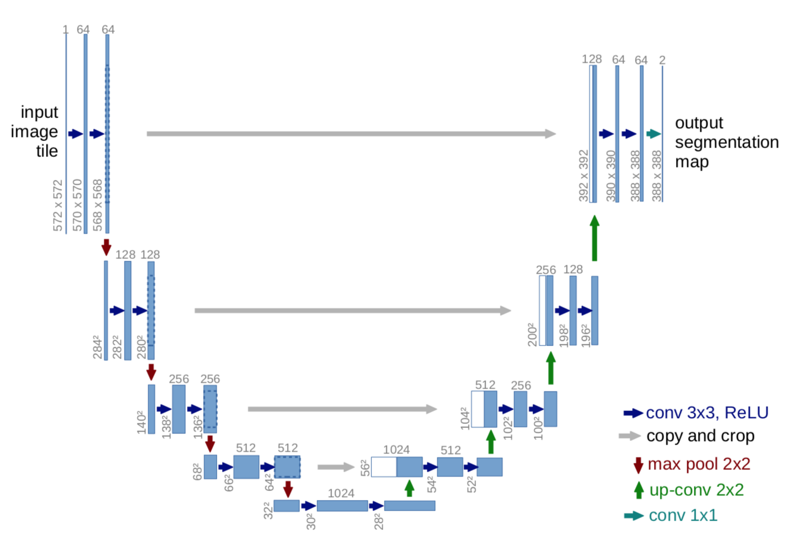


**Figure 4.** U-net model architecture, figure borrowed from the original paper. The U-net used in this research is adapted for 224 bands.

Bitfield encoding requires of hyperbolic tangent as activation function and the output neurons are the size of the primary classes. At the end of the network a threshold is applied. If the logit value of the output is higher than the threshold, the primary polimer is predicted. Creating this way, bitfield vectors (multi-label predictions) instead of a single prediction.

## Experiments and Results

- OD:
  - Baseline : U-net, the model is trained with Overlaps
  - Training with overlaps: U-net and bitfield encoding.
  - Training with only primary classes: U-net and bitfield encoding.
    - [Train] The train data does not contain overlap, but the validation does.
    - [Train and Validation] The train and validation data does not contain overlaps
- COD:
  - Baseline: U-net, the model is trained with overlaps.
  - Training with Overlaps: U-net and bitfield encoding.
  - Training with only primary classes [Train]: U-net and bitfield encoding,
  - Baseline-Spectral Normalization: Baseline experiment with Spectral Normalization preprocessing.

All experiments go through hyperparameter search, tuning learning rate and patience for all experiments and bitfield experiments additionally tuned threshold and activation function.

## Experiments and Results

| OD experiments | Metric per class | | |
|---|---|---|---|
| | F1-Score | Precision | Recall |
| Baseline | 0.938 | 0.936 | **0.945** |
| Training With Overlaps | **0.941** | **0.958** | 0.930 |
| Training with only primary classes [Train] | 0.425 | 0.481 | 0.549 |
| Training with only primary classes [Train and Validation] | 0.460 | 0.511 | 0.586 |

**Table 1.** Quantitative results from experiments performed with the OD. The metrics per class show that bitfield encoding can outperform or at least reach the performance of the baseline approach.

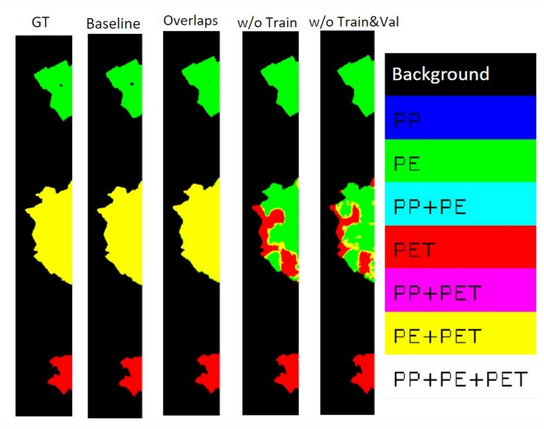


**Figure 5.** OD qualitative results. Baseline and Training with overlaps experiments predict all pixels almost perfectly. When training with only primary classes, one of the polymers from the overlap combination is predicted.

| COD experiments | Metric per class | | |
|---|---|---|---|
| | F1-Score | Precision | Recall |
| Baseline | 0.801 | 0.840 | 0.744 |
| Training With Overlaps | 0.644 | 0.658 | 0.654 |
| Training with only primary classes [Train] | 0.232 | 0.287 | 0.235 |
| Spectral Normalization | **0.985** | **0.991** | **0.979** |

**Table 2.** Quantitative results from experiments performed with the COD. The metrics per class show that spectral normalization preprocessing is useful for COD dataset, where there are areas with reflection and over exposition.

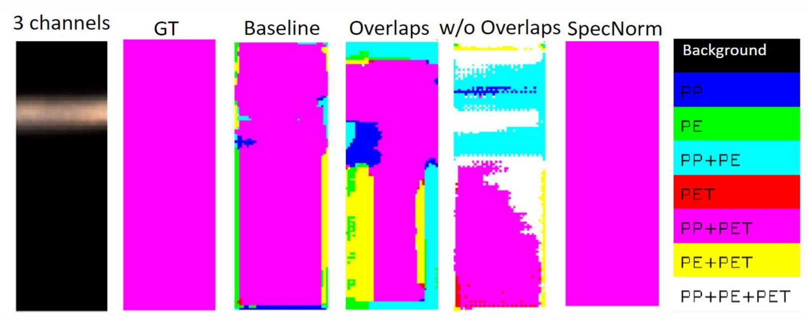


**Figure 5.** COD qualitative results. Baseline and Training with overlaps experiments predict all pixels almost perfectly. When training with only primary classes, one of the polymers from the overlap combination is predicted.

- From the results from Table 1 and Figure 5 we can ensure that bitfield encoding is a feasible approach for the overlaps task. However, there are some steps that need to be taken to be able to only train on primary classes and detect overlaps.
- From the results from Table 2 and Figure 6 we can conclude that spectral normalization is an important preprocessing in polymers segmentation.

## Conclusions

- We presented bitfield encoding, a new approach for multi-class and single-label problems where the classes are the combination of others. This encoding achieved the performance of a standard approach when is trained with overlaps.
- We executed a hyperparameter search that leads to two conclusions: Bitfield encoding should be used with Hyperbolic Tangent due to its linearity around zero.
- Regarding preprocessing we can say that spectral normalization is highly needed, since it removes lighting information that might bias the network and learning.
- We can also conclude that bitfield encoding requires another twist to be trained with only primary classes and detect overlaps. Future work should work in this direction, as is appointed as the goal.

## Acknowledgements

- This project is a collaboration between the Computer Vision & Data Science and Circular Plastics Professorships
- We would like to thank Prof. Petia Radeva and Bhalaji Nagarajan from University of Barcelona for the insightful discussions.

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## References

[1] UNEP. Single-use plastics: A roadmap for sustainability, Jun 2018
[2]Olaf Ronneberger, Philipp Fischer, and Thomas Brox. U-net: Convolutional networks for biomedical image segmentation, May 2015.