Exploratory analysis of plastics

In this tutorial an exploratory analysis on technical polymers typically for industrial recycling applications is summarized.

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Outline

Exploratory analysis are often the very first step after the acquisition of data from a camera system. The typical aim is to explore the information content in data, to get an image about the acquisition quality and often get an idea about potential suitable preprocessing configuration.

In this tutorial various plastics are investigated by NIR line-scan HS imaging. Different spectral properties of the objects are explored.

Data, Samples & Measurement

Download the example project Various plastics from the download section.

Various plastics / plastics:

<table>
<thead>
<tr>
<th>Title / plastics</th>
<th></th>
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<tbody>
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<td>Plastics</td>
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<tr>
<td>Donor</td>
<td>Markus@PP</td>
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<td>- Specim N17E slit30um,</td>
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<td>- KOWA F8</td>
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<td></td>
<td>- Perception System</td>
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Start the project

Install the example project by double click on the downloaded file and follow the instructions of the installer.

Open the Perception Studio program (e.g. from a link on your desktop) and change to the Start perspective.

Switch to example projects and select "Various plastics" from the list shown in the Start perspective.

Now, all data are loaded into the Perception Studio program, please give the system some seconds time to load all the data (watch the progress bar).

Explore HS data of plastics

Change to the Explore perspective and select the HS cube "plastics" from the project browser.
In the Explore perspective the Hyperspectral data loaded (data set plastics) is visualized by an image in the center of the perspective as well as a spectra view on the bottom and an cube intersection view to the right.

Scene view

In the scene view, the spatial resolved information of a Hyperspectral cube is visualized in form of a color or a monochrome image. The image information is obtained by applying a feature functions to the Hyperspectral cube.
As default, the preview feature is selected (in the ribbons Feature group) and results in a color image. By selecting a statistical feature like Mean, the mean per spectra is described in the image by its monochrome values.

**Spectra view**

In the spectra view at the bottom of the Explore perspective, spectral information of selected pixels are shown.

The loaded example data set comes along with predefined spectra sets. Their selection location in the scene is denoted by colored dot-markers. The markers color correspond to the spectra shown in the spectra view.

Move your mouse in the scene to see the spectral information underneath the mouse pointer in white color.

**Spatial vs. spectral view**

In this view the intersection of the Hyperspectral cube by a plane is visualized. In the scene view, a red line denotes the location for intersection.

Move the intersection marker (the red line) from left to right and inspect the spatial vs spectral view. The vertical axis correspond to spatial axis, the horizontal axis to the wavelength axis. The gray values in this view correspond to the cubes intersected values. The values of the cube in this example are relative reflectance values (1=100%).
Explore the spectral information

The loaded example data come along with a bunch of predefined spectra sets. Have a look in the spectra view and study the shown spectra sets of selected plastics.

A spectra set is visualized by an area and a line in between the area. The area corresponds to the variance region of selected spectra and the line to the mean of selected spectra. The spectra set of PVC (cyan) shows a large portion of variance. Move your mouse in the scene to understand the difference of both selected plastic plates (cyan dot-markers on it).

The left PVC plate (cyan markers) comes along with less reflectance than the right one - this results in the variance area of the cyan spectra set.

Note the absorption bands of the PVC spectra - one large is shown at ~1200nm while an other large one is shown at ~1400nm. The bands shown are characteristic for the molecule vibration of PVC. Compare the PVC spectra to other spectra in the scene - each spectra set has its own shape. By studying the literature of NIR spectroscopy, the following illustration was carried out. It shows the position of absorption bands in the NIR range resolved by molecular combinations:
There are C-H bondings causing the absorption of light at specific wavelength positions - this effect gets visible in the spectra of this example by the reduced amount of light reflected by the samples at specific wavelength positions (absorption bands).

By applying preprocessing to the spectra, the spectra are transformed in a form most properly for information extraction. Select the preprocessing method "1st derivative" from the ribbons Preprocessing group and analyze the spectra.

As you can see, the derivative of plastic spectra reduces the variance in the spectra and magnifies the absorption band positions. Since the spectra are now much better separated, the 1st derivative seem to be a proper preprocessing method when the separation of plastics is targeted. Note also the spatial vs. spectral view: when 1st derivative is applied to the data, the spectral information of different plates is clearly distinguishable.

Explore the nature of information nested

See the photography of the plastic plates for reference (available in chapter "Data, Samples & Measurement" of this tutorial).

Switch between different preprocessing modes and select Preview in the ribbons Features group. In the main view, a color image is shown. The color information of pixels shown give a measure on the "nature" of observed spectral information.

Pixels with similar spectral information are shown by similar, while distinct spectral information is shown by distinct color information.

Hint: Visualize the spectra underneath your mouse pointer (shown in the spectra view by white color) to investigate into the spectral information behind each pixel in the scene.
Above image summarizes the output of the preview method gained from reflectance data, while the next image shows the preview of spectra of the 1st derivative.

The preview method let us assume that all PA plastics are of similar spectral information since the objects come along with similar color information. Furthermore, the preview of spectra of 1st derivative comes along with higher color contrast compared to results without preprocessing. Since the 1st derivative rejects bias information from spectra interfered e.g. by different lighting intensities, it is good practice to reject this information if the actual chemistry of objects is of major interest. Consequently, the gained preview for plastics of 1st derivative more likely describes the actual chemistry of objects. Our expectation that chemically different objects are described by different color is met more likely when 1st derivative is set as preprocessing – additional bias information is rejected from the spectra.

This further improves by applying the 2nd derivative as preprocessing to the data (shown below).
Now, the color contrast in the image seem to have a quite large value. There are some plastic plates which come along with a distinct spectral nature like PA vs. PMMA. On the other hand, the preview also shows noise in the data which is consequently a result of higher order derivatives - see the PVC sample. Note: the noise of the PMMA sample seem to be of a smaller value compared to the PVC sample. This behavior corresponds to the fact that the dynamic of PMMA is less compared to PVC - PMMA causes a stronger "signal" compared to PVC. See some notes to the spectral dynamic of these objects below.

It is noticeable that one part of the PTFE object get colored differently (dark bluish part). By investigating the object a thin plastic label was recognized. So the dark-bluish region is caused by the spectra of this thin label. Please note: We see the influence of the thin label only for spectra of higher order derivative.

When investigating into the results gained after normalization, a blurring effect on the objects borders get visible - see the next image:

Compared to the results without normalization (first image gained by preview of reflectance data), more color contrast can be recognized. Therefore, the distinction of the plastic spectra has increased as a result of normalization. By normalization, each spectra in the scene is transformed into the same value range. Therefore, the absolute value of the spectra get lost. While normalized spectra are much more independent from light intensity variation, also the negative effect of a magnification of very weak spectra has to be taken into account. This effect gets clear by analyzing the influence of normalization to background spectra - the background gets very noisy. In addition the borders of objects get blurred.

Hint: An established way to handle these negative effects is obtained by segmentation of the noisy image afterwards. The spectral dynamic feature mentioned below might be a proper feature for segmentation - the value of background is quite distinct from foreground (plastic plates).

The influence of the shiny letters (description on plates) on the objects seem to be quite high without preprocessing, but gets very low for higher order derivatives (constant information are rejected by the derivative).

In all illustrations the PTFE object (Teflon) is most likely comparable to the background of the measurement. The background is a white ceramic tile that comes along with almost no spectral bands in the observed spectral range. This is also true for PTFE (Teflon). Consequently, the preview information is similar for both objects regardless of the preprocessing.
Summary: from inspecting the preview feature of observed plastics, we can assume that a preprocessing like 1st or 2nd derivative reveal most likely information from the data which corresponds to the actual chemistry. The 2nd derivative comes along with the largest degree of noise in the spectra and preview respectively. A thin plastic label has got "visible" on the PTFE (Teflon) if a higher order derivative was applied beforehand. The painting on the plastic plates disturb the spectra information of the underlying material enormous. Some reflections can be recognized in the data caused by the shiny color - the spectra does not correspond to the material.

Explore statistical information

Here some statistical features get employed to explore information nested in the HS data of plastics. See the photography of the plastic plates for reference (available in chapter "Data, Samples & Measurement" of this tutorial).

Reflectance of objects

Set preprocessing to Intensity and select Mean in the ribbons Features group. In the main view, a gray value image is shown. Each pixel value correspond to the mean of the reflectance spectra behind.

Hint: Visualize the spectra underneath your mouse pointer (shown in the spectra view by white color) to investigate into the spectral information behind each pixel in the scene.

As shown in the image above, the NIR reflectance of all PA plastics is much smaller compared to a plastic like PVC.

Note: since the reflectance is measured in the NIR range (~1000-1700nm), the reflectance in the visual range (~400-750nm), like it is obtained by a monochrome camera, can be strongly different.

Spectral dynamic

Set preprocessing to Intensity and select Dynamic in the ribbons Features group. In the main view, a gray value image is shown. Each pixel value correspond to the selected feature of the reflectance spectra behind.

Hint: Visualize the spectra underneath your mouse pointer (shown in the spectra view by white color) to investigate into the spectral information behind each pixel in the scene.
From the image above the spectral dynamic in the NIR range can be investigated. The dynamic gives us a measure on the degree of modulation caused by an object to light.

A strong value in dynamic can indicate strong spectral bands caused by an observed object. Typically objects of large dynamic are detectable with more confidence compared to objects of a small amount.

Consequently, the objects of material PVC can be assumed to be detectable with less confidence compared to the object of material PE. Their dynamic is significantly less in value compared to PE. The plastic of material PTFE (Teflon) comes along with a very small value of dynamic. This is obviously, since PTFE doesn't show absorption bands in the spectral range of the measurement (1000-1700nm).

**Other statistically features**

By selecting between different preprocessing and different statistically features, various information can be extracted from the HS data.

The following example should highlight the plastic plates that causes a spectral pattern characteristic by the highest slope value.

Set preprocessing to 1st Derivative and select Max in the ribbons Features group. In the main view, a gray value image is shown. Each pixel value correspond to the selected feature of the 1st derivative (slope) of spectra behind.

From the image above, it is obvious to see that the object of material PE causes spectra with strongest slope information - the "spectral pattern" of PE is characterized by the highest slope value compared to all other plastics in the scene. The plastic PTFE comes along with the smallest slope value. This is obvious, since PTFE (Teflon) don't shows absorption bands in the spectral range of the measurement (1000-1700nm).