Advanced SWIR Spectroscopy for Next-Generation Fabric Identification

Introduction

Textile sorting is increasingly becoming a multifaceted challenge that requires accurate material classification. The fashion industry's reliance on non-biodegradable synthetic fibers, mainly due to their versatility and cost-efficiency, introduces a unique challenge for its recyclability. Complicating matters further, the prevalence of blended fabrics, incorporating both natural and synthetic fibers, requires intricate separation during the recycling process. Treatments with dyes, chemicals, and finishes, add yet another layer of difficulty for the reuse of these materials.

This white paper will explore the cutting-edge solutions and technologies that play a pivotal role in overcoming the challenges set by the intricate world of textile sorting, while also promoting sustainable practices within the textile industry.

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Determining the Level of Accuracy in Textile Blends

The need to better understand and navigate the complexities of textile recycling and waste reduction led us to ponder a crucial question: "What level of accuracy can be achieved when it comes to identifying and classifying textile blends?"

Below is an exploration of our approach and breakthroughs in this emerging challenge.

Innovative Benchmark Study Using SWIR Spectroscopy

Our comprehensive benchmark study harnesses the capabilities of our Short-Wave Infrared (SWIR) hyperspectral cameras:the L-EOS 1.7 and L-EOS 2.5.

The L-EOS 1.7 spans the 900-1700 nm range, while the L-EOS 2.5 extends its reach to 900-2500 nm. These cameras are not just tools; they represent a paradigm shift compared to ordinary RGB cameras. Somes textiles have a similar trace in the SWIR and the visible, so a RBG camera will not be able to classify the different textiles, this is where a hyperspectral camera with high-sensitivity distinguishes itself. Most of the textiles have significant pics in the SWIR spectrum. With these advanced capabilities the L-EOS uncovers an abundance of information from textiles invisible to the naked eye.

What is hyperspectral data

Hyperspectral imaging is a technique used to capture and analyze the spectral information of a scene or object. Unlike traditional imaging techniques in the visible, which capture images in only three spectral bands (red, green, and blue), hyperspectral imaging captures data across hundreds of continuous spectral bands covering the visible and infrared bands of the electromagnetic spectrum.

In hyperspectral imaging, each pixel in an image contains information about the emission, reflectance or transmission of light at different wavelengths. This information can be used to identify and distinguish between materials, identify chemical compositions, and analyze the physical properties at all points of the scene or object being imaged.

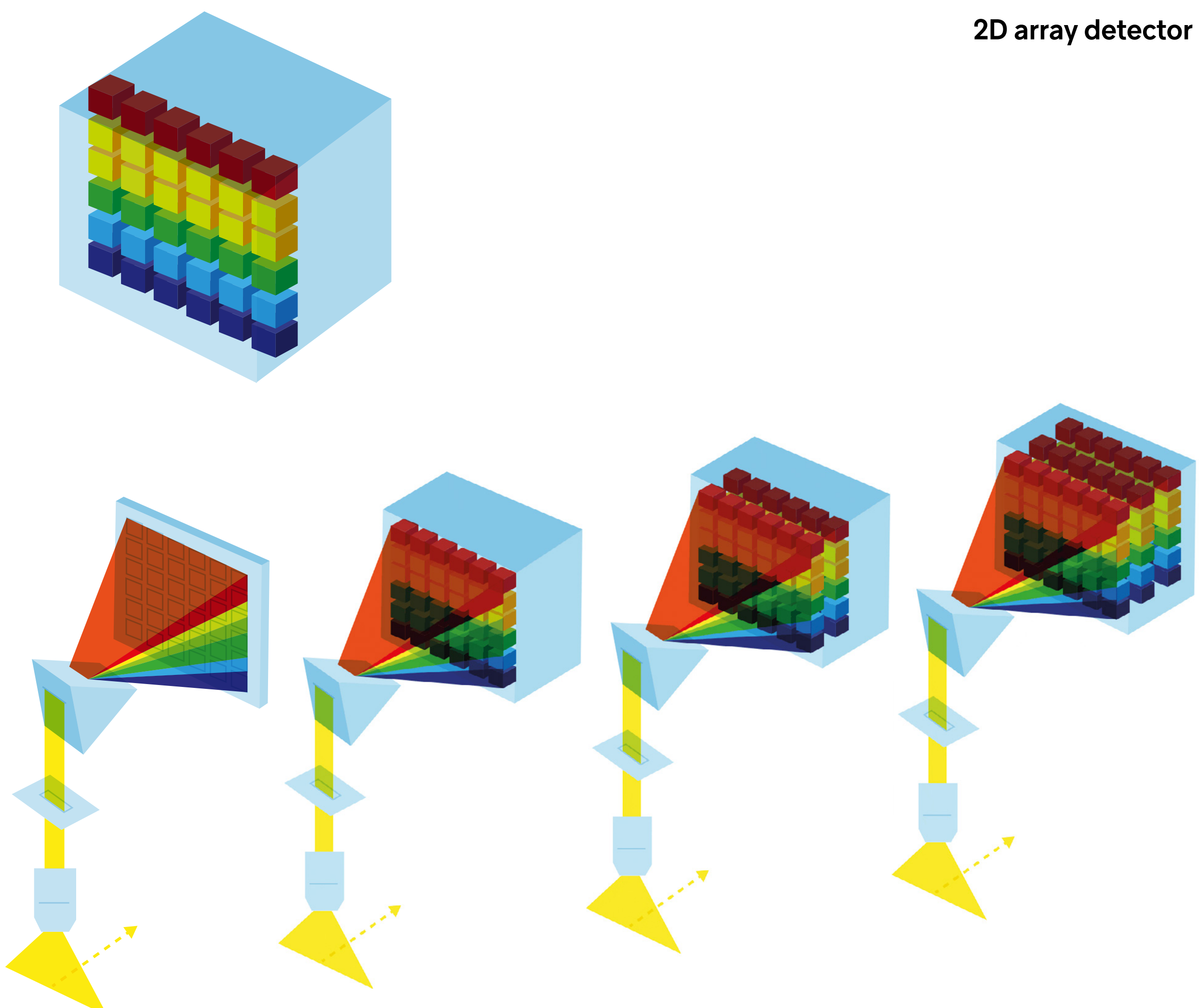


Figure 1. A representation of a hyperspectral data cube

The Significance of Hyperspectral Testing

Hyperspectral testing represents a significant leap forward for improved accuracy in textile blend analysis. This technology offers meticulous control over textile illumination, ensuring consistent and high-quality data acquisition. Hyperspectral cameras enable the capture of images at various wavelengths, providing insights into the unique spectral signatures of different materials within textile blends.

Figure 2. Set-up L-EOS benchtop

Key Features of L-EOS 1.7 and L-EOS 2.5 Hyperspectral PushBroom Cameras on a Benchtop:

Spectral Range

Covering the crucial 900-1700 nm and 900-2500 nm ranges, respectively, these cameras capture a broad spectrum, ensuring a comprehensive analysis of textile blends.

Spectrometer

Provides precise and rapid analysis of industrial materials, offering high resolution, sensitivity, and versatility for quality control and process monitoring applications.

Thermoelectric cooling

Offers a compact, maintenance-free solution with no moving parts, high reliability, long lifetime, low dark current, and minimal readout noise in electronic devices.

Speed

Medium speed of the translation is 100 mm/s and the maximum speed is 199 mm/s.

Tray dimension

30 x 30 cm.

SWIR Illumination

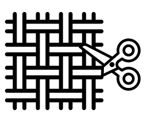
Enhances imaging capabilities by revealing details that are otherwise obscured in the visible spectrum.

Designing a Comprehensive Testing Set and Training set

A distinct testing set was developed to determine the accuracy of classifying textile blends. The set includes a diverse range of textiles, featuring various colors and known blends, such as viscose/cotton, viscose/nylon, and polyester/viscose. To ensure the highest accuracy of our algorithms, the purest textiles are to be incorporated during this stage.

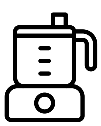
We then implement two training sets that cover a spectrum of blend ratios from 0% to 50%, with increments of 10% blend by weight. This provides us with the necessary data to develop and fine-tune our algorithms and models for accurately determining blend percentages within textiles. To create the blends, we shredded them with scissors, mixed them in water, blended them in a food blender, filtered them using paper filters, and air-dried them. It's crucial to ensure thorough drying to avoid water traces and water absorption, as these can conceal water peaks. The blends on the left are a mix of nylon and polyester, while the four tests on the right are a combination of viscose (yellow and gray) and cotton (black and red). Black is quite difficult to detect in hyperspectral because of the absorption. The inherent difficulty arises from the absorption characteristics of black materials. Unlike other colors that reflect or emit light, black absorbs light across a broad spectrum. Consequently, black objects often exhibit a limited and indistinctive spectral signature in hyperspectral data.

1. **shredded with scissors**



2. **mixed in water**

3. **blended**



4. **filtered with paper filters**

5. **air-dried**

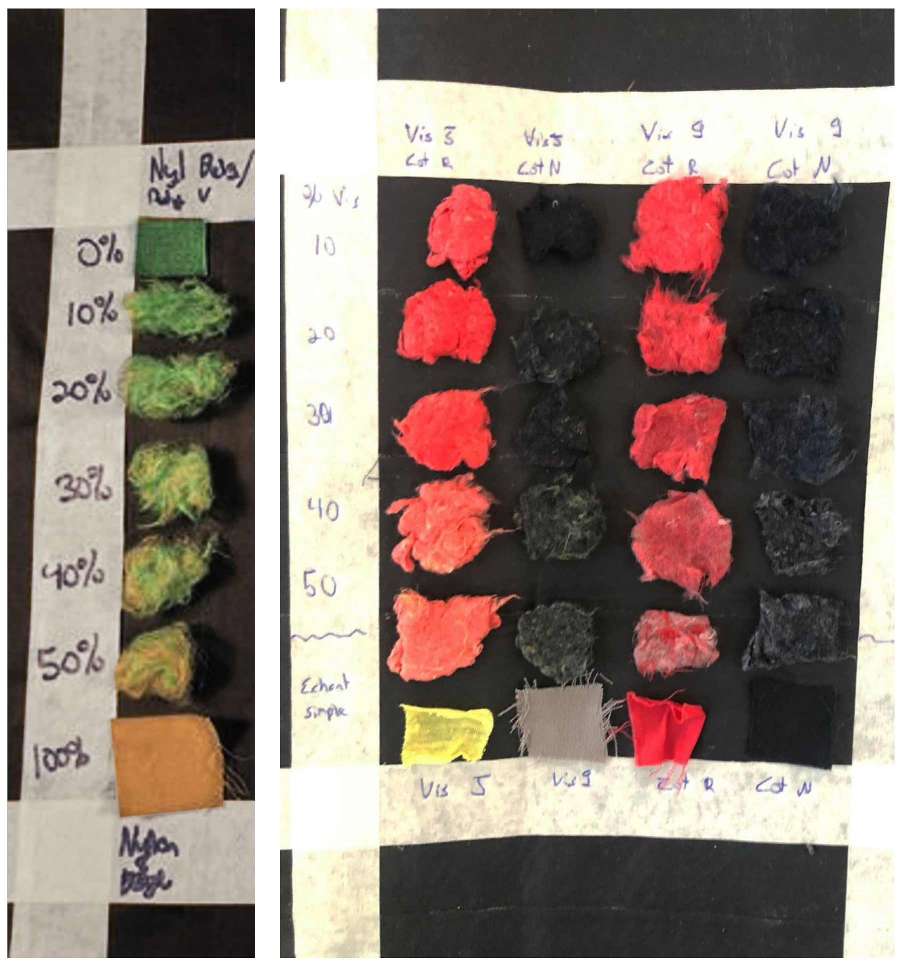


Figure 3. Testing set (left) and Training set (right)

Refining the Approach through Pre-Analysis Treatment and Pre-Processing

The methodology comprises three key phases: pre-analysis treatment, pre-processing, and concentration estimation techniques. In the pre-analysis treatment we aim to clean the data to only have the relevant one. First three hyperspectral cubes are captured per sample platform to ensure uniformity and a 3 x 3 median filter is applied to each of these cubes for noise reduction and data enhancement. These filtered cubes are then averaged for each platform, followed by data normalization, object selection, and binary filtering for segmenting and separating samples. The pre-processing stage includes various techniques such as mean-centering, 1st and 2nd derivatives combined with mean-centering, and wavelength selection tailored to extract the most relevant spectral information.

Methodology

Pre-analasis

Cleaning the data

Pre-processing

Enhancing the data

Using different techniques for concentration estimation

Multivariate Regression

Multivariate Curve Resolution

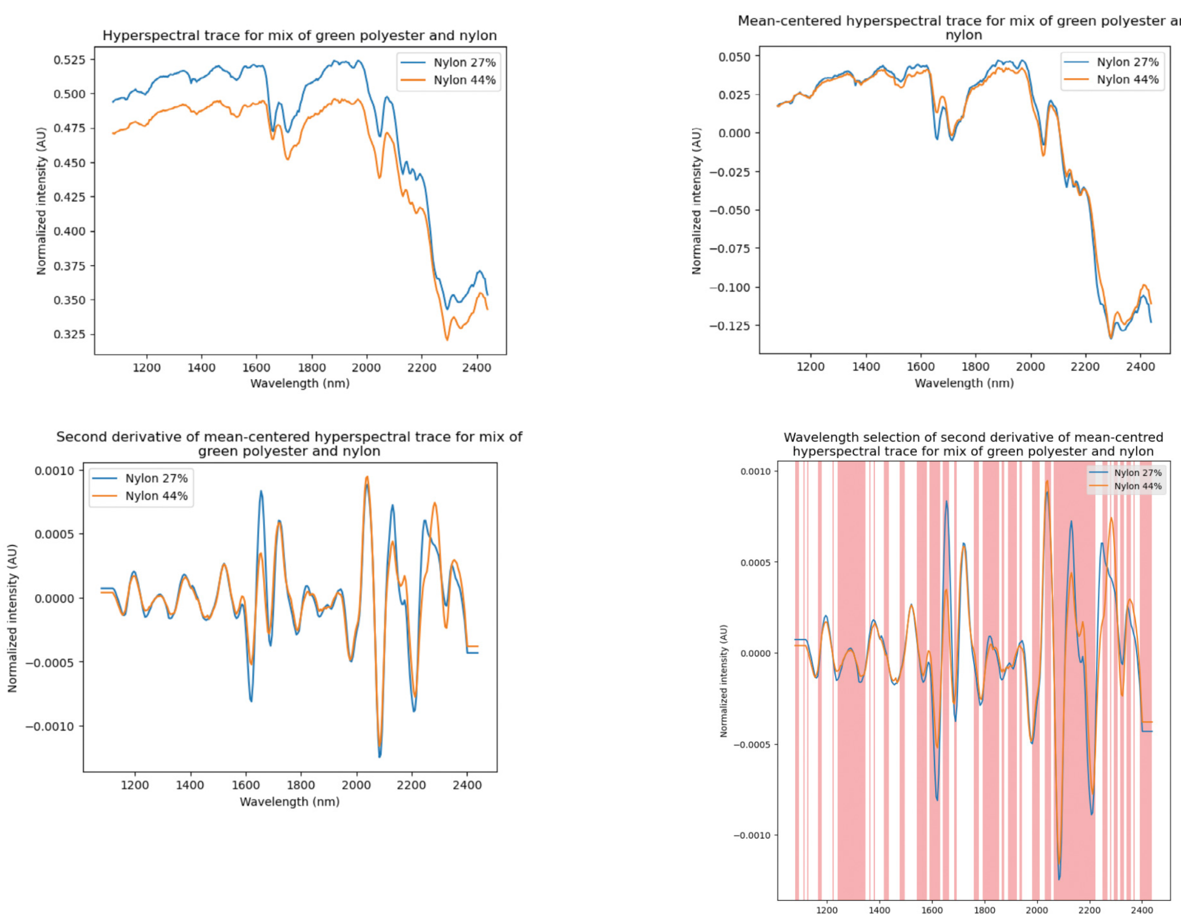


Figure 4. Example of all the pre-processing stage (mean-centering, 1st and 2nd derivatives combined with mean-centering)

Using Algorithms for Accurate Concentration Estimation Techniques

Different concentration estimation techniques are employed to assess blends within textiles, including Multivariate Regression (MR) and Multivariate Curve Resolution (MCR). Each technique offers unique insights into the accuracy of blend ratio estimation, providing valuable information on the suitability of these methods for textile blend analysis.

The first technique that we use is Multivariate Regression. It's a statistical analysis technique in two steps used in data analysis and machine learning to predict a target variable. The goal is to find a mathematical relationship that best explains the variation in the dependent variable by considering the combined effect of multiple independent variables. It requires a training set date to work. In contrast, Multivariate Curve Resolution (MCR) follows an iterative method for the concentration estimation. It solely requires pure data and the concentration estimate always equals one, that is not the case with MR.

Root Mean Square Error (RMSE)

The standard deviation of errors, RMSE, is used to evaluate the accuracy of predictive models for textile blends. It quantifies the typical prediction error by comparing model-generated predictions to actual values in a testing dataset. An accuracy level for textile blends is indicated when predictions are within twice the RMSE value, covering approximately 95% of the results.

$$\mathbf{RMSE} = \sqrt{\frac{\sum (y_i - y_p)^2}{n}}$$

$\mathbf{y_i}$ = acutal value
$\mathbf{y_p}$ = predicted value
$\mathbf{n}$ = number of observations/rows

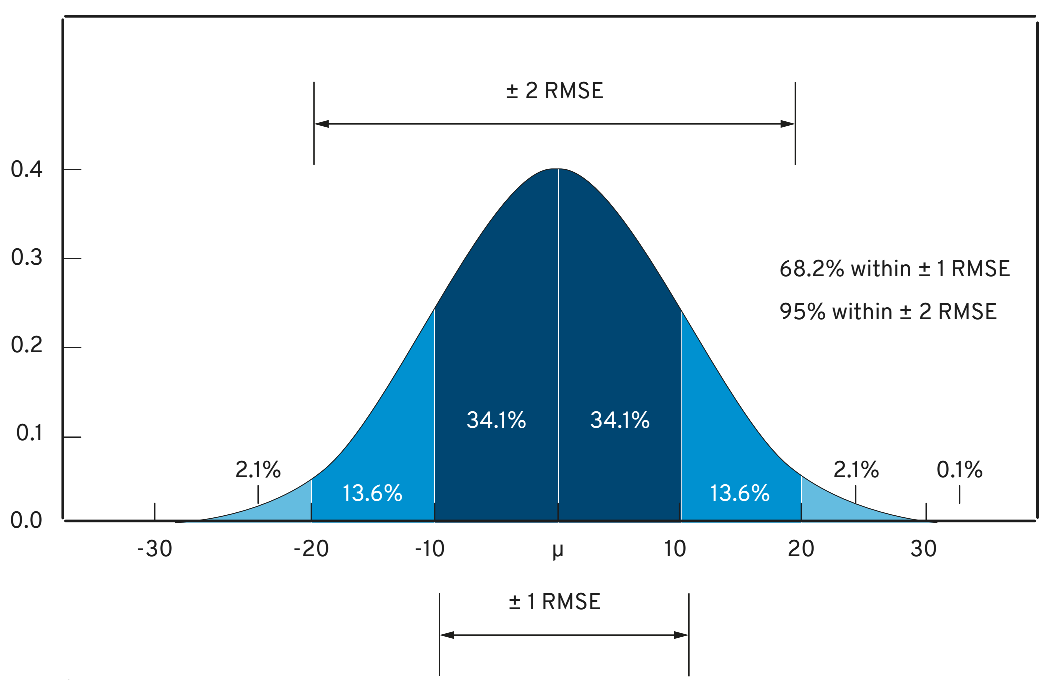


Figure 5. RMSE curve

Unveiling the Accuracy of Textile Blends Identification

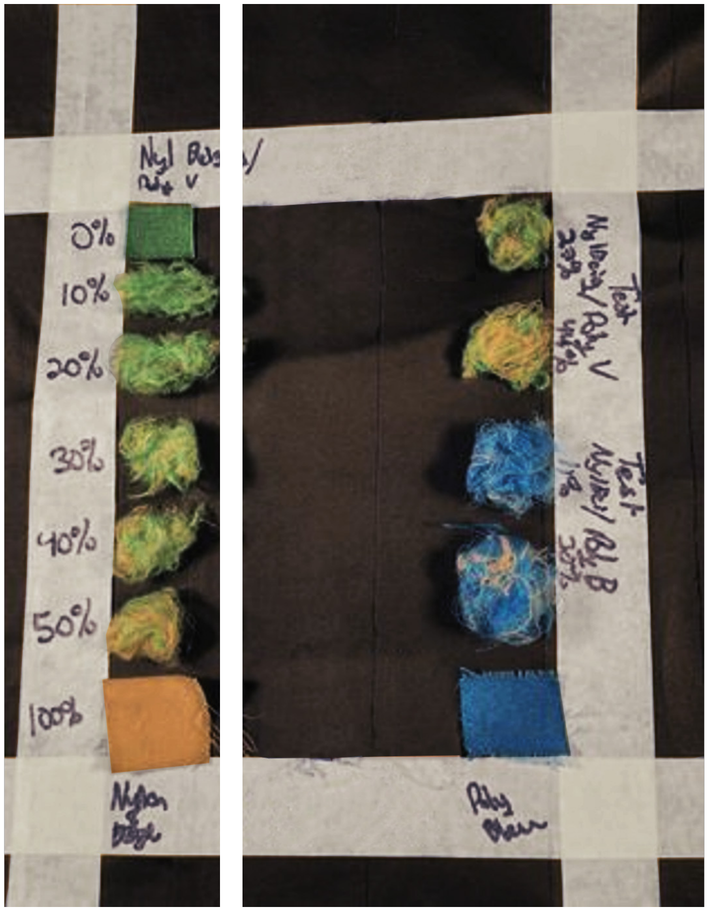


Figure 6. Testing Set (left) and Training Set (right)

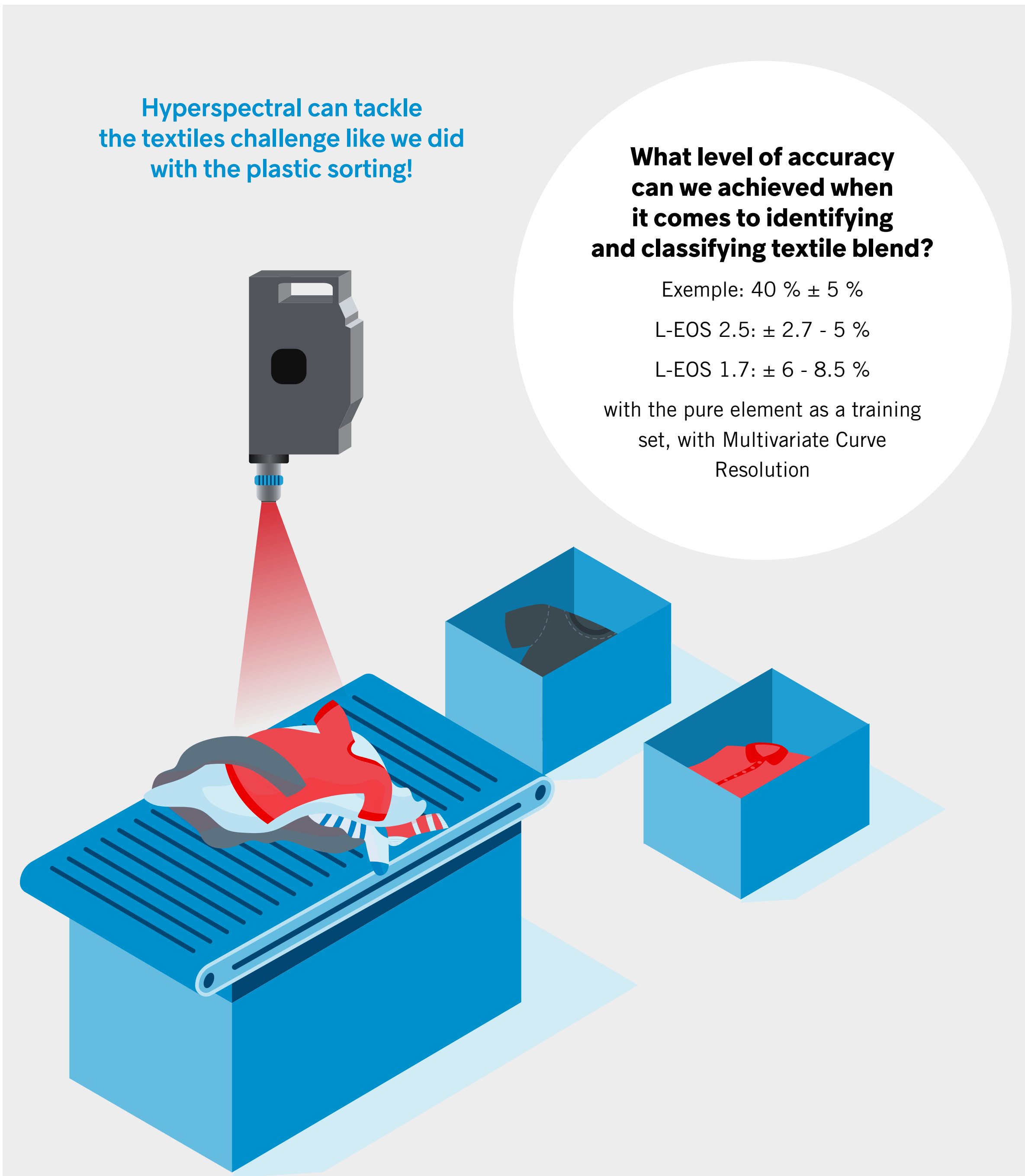
Results for Multivariate Regression and Multivariate Curve Resolution showcase promising accuracy levels. The training set, containing various blends, demonstrates the effectiveness of these algorithms. Notably, accuracy varies by blend type, highlighting the complexity of predicting different blends. Observations include blend-dependent minimum detectable concentrations, spectral variations in wet and dry fabrics, and the importance of trimming wavelengths for precision.

Fabrics mixture	RMSE MR	RMSE MCR
Beige nylon / Green polyester	1.35	0.28
Blue nylon / Blue polyester	2.69	3.54
Blue cotton / Grey viscose	6.34	7.04

Figure 7. Results for Multivariate Regression (MC) and Multivariate Curve Resolution (MCR)

Final Remarks and Conclusion

Achieving a high level of accuracy in identifying and classifying textile blends is crucial for efficient recycling, waste reduction, and sustainable practices. Through the benchmark study and the use of SWIR spectroscopy, substantial progress has been made. Advanced hyperspectral technology enables accuracies within a range of ± 2-8% depending on the hyperspectral camera use and the textile blends involved, revolutionizing textile industry sorting and recycling. This progress underscores the importance of continued research and innovation in textile analysis and hyperspectral imaging, with the ultimate goal of revolutionizing the textile industry's sorting and recycling practices.



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