

NIR - SPECTROSCOPY

Sorting technology comparison



Table of contents

1. General	3
1.1. Material analysis by NIR spectroscopy	3
1.2. NIR spectrometer KUSTAx.xMSI.....	7
2. State of the art	8
2.1. NIR hyperspectral camera / LLA Instruments GmbH.....	8
2.2. NIR spectrometer unit / Manufacturer A	10
2.3. NIR spectrometer unit / Manufacturer B	10
3. Comparison NIR process measurement	11
3.1. Visualisation of sample identification / LLA Instruments GmbH.....	12
3.2. Comparison of applications	13
3.3. NIR spectroscopic evaluation of waste paper.....	14
3.4. Waste paper recycling	17

1. General

1.1. Material analysis by NIR spectroscopy

The Infrared Spectroscopy (IRS) is one of the most powerful analytical techniques for the identification or analysis of organic samples based on the excitation of energy states in molecules by IR radiation. This technique permits direct conclusions about the presence and where possible concentration of infrared active functional groups. Also the Near Infra Red Spectroscopy (NIRS) is based on the excitation of molecular vibrations by electromagnetic radiation - but the radiation detection is performed only in the short infrared wavelength range i.e. the range between 780 nm to 2500 nm. In this wavelength range the overtone and combination bands of the fundamental molecular vibrations are to be found. The absorption bands caused by the molecular vibrations of the samples are not directly interpreted but analysed with statistical methods.

The NIR spectroscopy is often used for rapid analysis of samples and sample mixtures in process analysis. Here the infrared radiation generated by halogen lamps is directed on the sample surface. The radiation reflected by the sample is spectrally divided and detected as function of the wavelength (see example figure 3). Depending on the sample material, specific wavelength ranges are particularly strongly absorbed. That occurs at wavelengths that correspond to the resonance frequency of the excited molecules. From the spectrum, characteristic for each material, by means of mathematical analysis and comparison with reference spectra the sample material may be determined reliably.

To obtain sufficient information about the sample composition, it is necessary to measure the sample in the relevant wavelength band with a high spectral resolution. For the identification of polymers the wavelength band of the first overtone bands of the CH stretching vibrations (between 1400 nm und 1900 nm) has been proven suitable. The number of measuring points in the wavelength band depends on the chosen measuring technique. Single photo diodes that are placed in the focal plane of a polychromator, generate only a small number of measuring points for the pre-determined wavelengths (minimal 8, at most 32). The characteristic absorption bands of the spectrum will therefore not be detected. NIR line cameras are clearly more flexible. The complete wavelength band is mapped on a detector line, were each detector is responsible for a small wavelength band. The number of detectors depends on the type of line camera and can be 128, 256, 512 or more.

In figure 1 to figure 3 three reflexion spectra of different paper products are shown. The spectra are recorded in the selected wave length band with 8, 32 and 256 equidistant measurement points. The quality and the information contents of the spectra diminish with the number of measurement point significantly.

Paper spectra are dominated by the water absorption bands at 1440 and 1920 nm. The contents of cellulose-, lignin- and ash as well as the contents of other additives cause a fine modulation of these dominant water bands. These modulations are only becoming clearly detectable at 256 wave lengths and whose analysis is performed in the first or second derivative. Using 32 wave lengths, the evaluation of paper is impossible. Reliable sample identification requires apart from a high spectral resolution, sufficient signal intensity and sufficient dynamic range also a reliable spectroscopic calibration of the measuring system. During the spectral measurements of the sample, the spectral information of the sample interferes with the spectral properties of the light source and the measuring system. Additionally, the latter changes over time. The measuring system is calibrated with a spectral standard in defined intervals, to obtain at all times a reliable identification, independent from the measuring system.

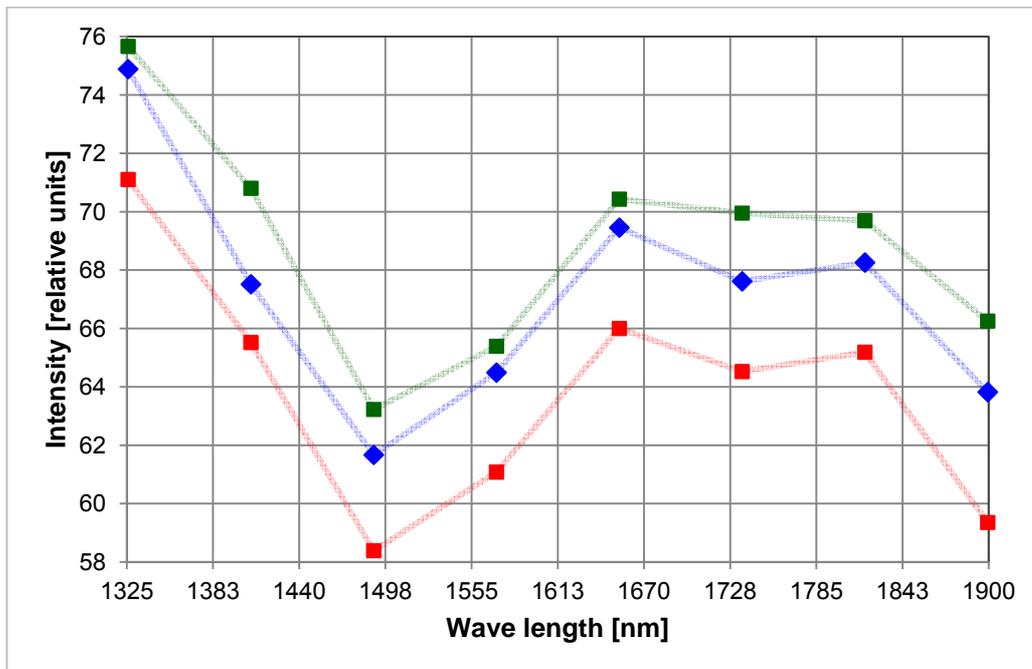


figure 1

Three paper spectra with each eight measurement points in the wave length range of 1325 nm to 1900 nm (office paper, magazine, carrier board). Only the rough shape of the spectra may be detected.

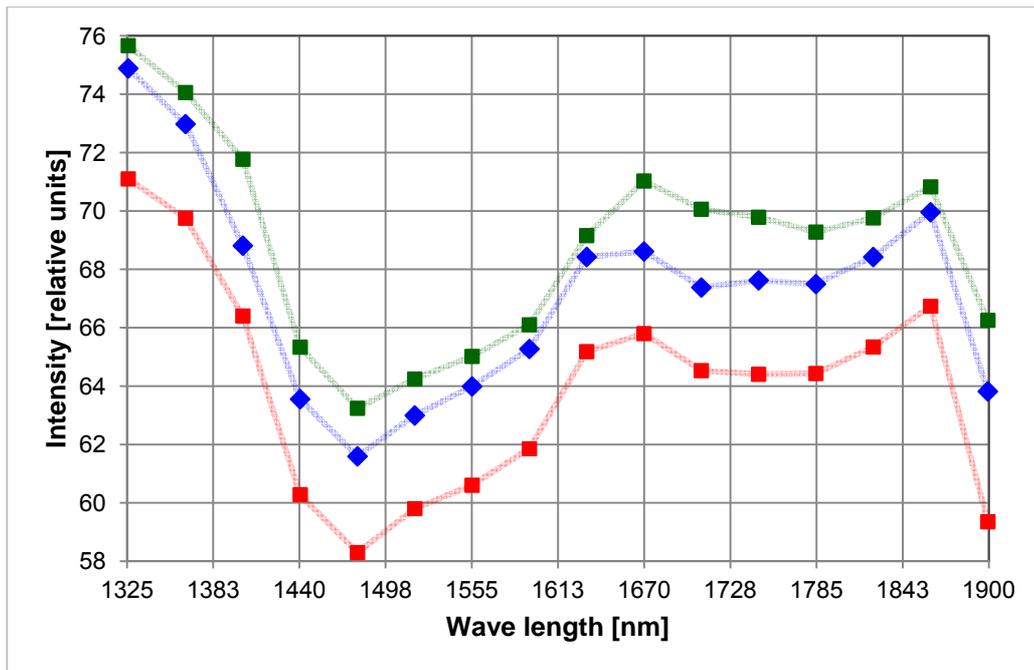


figure 2

Three paper spectra with each 16 measurement points in the wave length range of 1325 nm to 1900 nm. Only the rough shape of the spectra may be detected. Fine differences, resulting from the differences in paper composition may not be detected (office paper, magazine, carrier board).

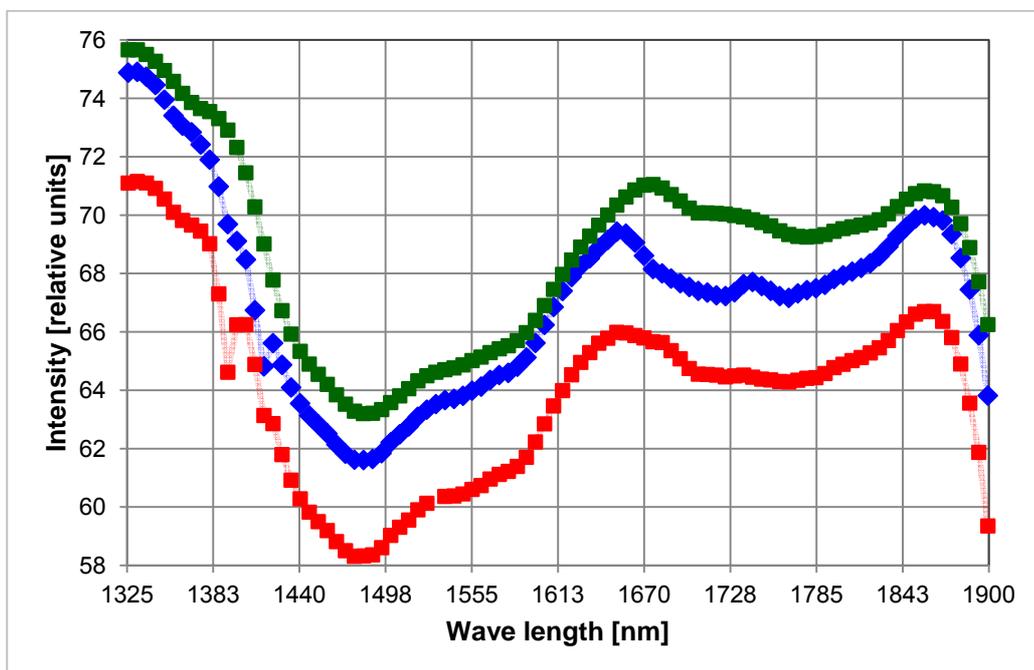
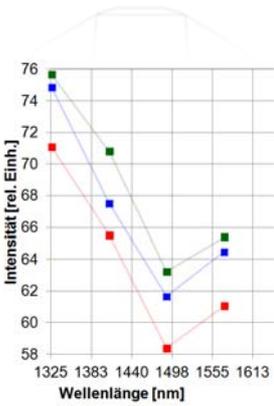
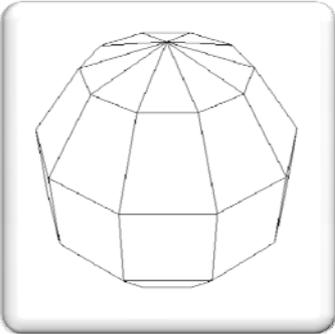


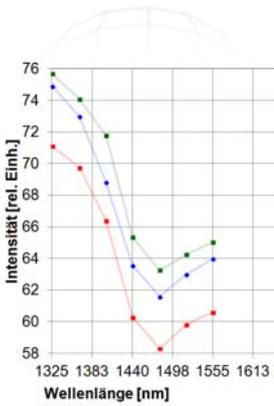
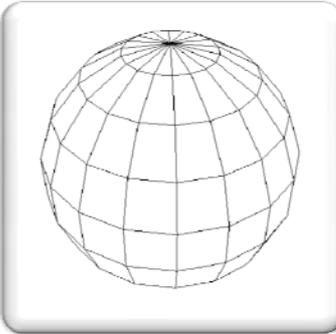
figure 3

Three paper spectra with each 96 measurement points in the wave length range of 1325 nm to 1900 nm. Fine differences in the spectra are clearly visible (office paper, magazine, carrier board). Untreated spectra recorded with KUSTA1.9MSI.

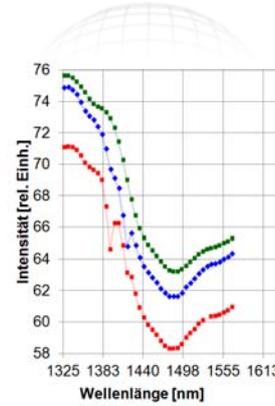
Comparison of the NIR spectrometer - example paper analysis



Manufacturer A



Manufacturer B



LLA Instruments GmbH

1.2. NIR spectrometer KUSTAx.xMSI

LLA Instruments GmbH is a manufacturer and supplier of spectroscopic measuring devices for chemical analysis. In particular for the sorting of material for material and energetic recycling purposes the imaging hyperspectral camera with an optional integrated colour sensor is offered. All measuring and optical components are designed modular and can be therefore by the machine builder adjusted to the particular sorting task.

The measurement systems KUSTA1.7MSI and KUSTA1.9MSI (KUSTAx.x.MSI) consist of the following OEM components:

- ▶ NIR hyperspectral camera KUSTAx.xMSI
- ▶ Industrial PC for camera control and data recording
- ▶ Control- and analytical software KustaMSI:
 - ▼ Control and monitoring of the hyperspectral camera
 - ▼ Data acquisition of the camera and analysis of the measurement data in real-time
 - ▼ Transfer of analysis results to plant control
 - ▼ Support of different hardware interfaces and data transfer protocols
 - ▼ Analysis routines and applications may be customised
- ▶ Illumination unit PMAmSI: The illumination unit consists of two parallel illumination lines (LU) which are slightly tilted. The integrated NIR lamps generate a small light strip on the conveyor belt. For different sorting tasks and conveyor belt widths different versions are offered.
- ▶ Installation bridge for stable connection of illumination unit and hyperspectral camera
- ▶ Optional: Air conditioned control cabinet with touch screen
- ▶ Optional: RGB colour line camera
- ▶ Optional: Automatic calibration for white calibration

2. State of the art

2.1. NIR hyperspectral camera / LLA Instruments GmbH

For material identification LLA uses a hyperspectral camera with an imaging spectrograph. Two lines of halogen penlights generate with reflectors on a conveyor belt a focussed light strip across the conveyor belt. The samples pass through the light strip (see figure 4). The radiation reflected from the samples is captured by the camera which is aligned vertically above the light strip. At the imaging spectrograph the spatial information of the measurement area mapped on the entry slit is retained across the slit height. The resulting image in the focal plane consists of a spatial and a vertically located spectral component. The matrix detector in the image plane records therefore for each image point of the entrance slit (pixel line from the detector matrix) contemporary the corresponding spectra on the vertical aligned pixel column. That permits line scanning of the samples with high frequency providing for each image full spectral and spatial information.

A combination of these line scans along a time axis provides a two-dimensional raster image with spatial and spectral information. Apart from the position and the size of the samples by the relevant spectra also the material composition of the samples may be identified. These analytical results of the sample stream are transferred in real time to process control.

The matrix detectors used in the hyperspectral cameras have a raster and 320 x 256 pixels in KUSTA1.7MSI) and 192 x 96 pixels in KUSTA1.9MSI. The 320 rows respectively 192 rows are used for spatial resolution and the 256 respectively 96 columns for spectral component. Based on the high number of measurement points in the spectra, the spectra are well suitable to identify small differences in the spectral reflexion properties of the samples to identify therefore the samples reliably.

Based on high spatial resolution and high scan rates of 270 Hz respectively 795 Hz also small samples may be detected and analysed on fast moving conveyor belts. Another advantage of the hyperspectral camera is the absence of mechanical i.e. moving components, making the technique robust for the use in industrial environments.

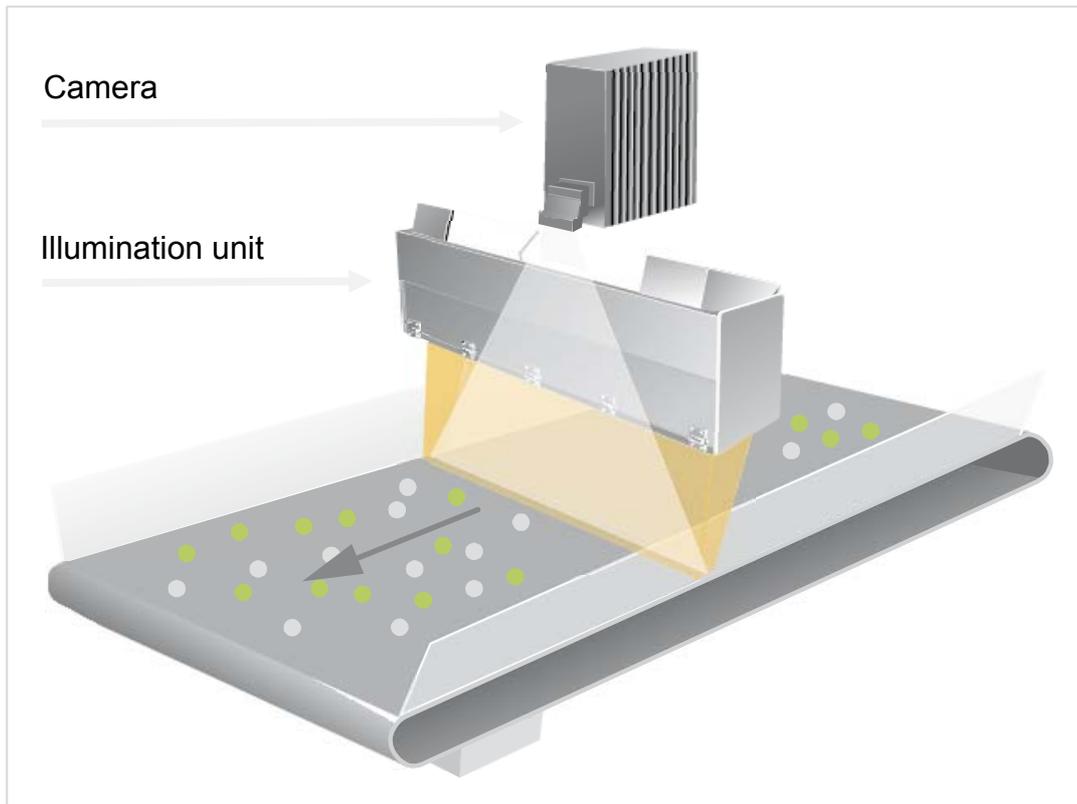


figure 4

Optical setup of KUSTAx.xMSI

Advantages NIR spectroscopy LLA Instruments GmbH

- ▶ No moving parts because of use of a hyperspectral camera as opposed to a scanner
- ▶ High spatial resolution based on large number of measurement tracks
- ▶ Highest information contents in comparison to the measurement systems of competitors:
 - ▼ LLA: 256 measurement points in the spectra at scan rates of 86.400 spectra/second (22.118.400 measurements/second)
 - ▼ A: 8 measurement points in the spectra at scan rates of 25.000 spectra/second (200.000 measurements/second)
 - ▼ B: 16 measurement points in the spectra at scan rates of 160.000 spectra/second (2.560.000 measurements/second)
- ▶ High spectral resolution assures analytical selectivity for material identification
- ▶ Qualitative and quantitative analysis of spectra in real-time
- ▶ Use of methods of digital image analysis (e.g. object recognition, figure 5)
- ▶ Modification of application routines without hardware changes
- ▶ Easy installation of application routines via remote control
- ▶ Development of customer specific software solutions

2.2. NIR spectrometer unit / Manufacturer A

Like the manufacturer B plant also the sorting plant of manufacturer A operates on the basis of a scanning NIR spectrometer. Two halogen pen lights generate across the conveyor belt a light strip. The samples pass through this light strip. A rotating mirror scans this light strip and directs the light emitted from the samples via the converging lens on a bundle of fibre optical cables. The major part of fibre optical cables of the cable bundle is connected to the entrance slit of a spectrograph. The remaining three fibre optical cables are each connected to one colour sensor. On the exit side of the spectrograph further fibre optical cables are connected to a NIR spectroscopic detector each. Because each detector is assigned to a specific wave length, only a few discrete measurement points in the technically possible wavelength range are captured by the spectrometer unit. This results in spectra with low information contents but the spectra may be gathered with a high scan rate. The repetition rate of the measurement is limited, as in the competing systems, by the processing speed of the spectrometer unit.

2.3. NIR spectrometer unit / Manufacturer B

This sorting plant uses a scanning NIR spectrometer. Two lines of single light bulbs generate across the conveyor belt a light strip. The samples pass through this light strip. A rotating polygon mirror continuously scans via a tilted mirror an illumination strip on the conveyor belt and directs the light reflected from the samples to a fixed mounted spectrograph. In the image plane of the spectrograph at predefined positions single NIR detectors are arranged. Because each detector is assigned to a specific wave length, only a few discrete measurement points in the technically possible wavelength range are captured by the spectrometer unit.

The new generation of manufacturer B sorting plants combines visual and NIR spectroscopy in one plant. Instead of a range of light bulbs this plant uses a single radiation source with uniform luminous area. The radiation source is together with the NIR spectrometer and the VIS detectors combined in one chassis.

The radiation of the radiation source passes a rotating polygonal mirror and hits the sorting samples on the conveyor belt. The reflected light from the samples passes the rotating polygonal mirror and is directed to the detectors right beside the radiation source. In the image plane of the spectrograph at predefined positions single NIR detectors are arranged. Because each detector is assigned to a specific wave length, only a few discrete measurement points in the technically possible wavelength range are captured by the spectrometer unit. This results in spectra with low information contents but the spectra may be gathered with a high scan rate. The repetition rate of the measurement is limited, as in the competing systems, by the processing speed of the spectrometer unit.

3. Comparison NIR process measurement

Component and characteristics	LLA KUSTA1.7MSI/ KUSTA1.9MSI	Manufacturer A	Manufacturer B
Measurement optics	Hyperspectral camera with adjusted NIR objective	Scanning mirror with subsequent optics and fibre cable bundle	Scanning polygon mirror with subsequent optics
	Valuation: The LLA hyperspectral camera has no moving parts and is therefore for reliable use in industrial environments particularly suitable.		
Spectrograph	Imaging spectrograph with detector matrix	Spectrograph with a small number of wave lengths	Spectrograph with a small number of wave lengths
NIR wave length range	950 nm – 1700 nm/ 1325 nm – 1900 nm	Not known	Not known
Number of measurement point in the spectra	256/ 96	≤ 8	≤ 16
	Valuation: The large number of wave lengths assures a high analytical selectivity for the LLA solution. The analysis of the measurements in the NIR spectral range requires the use of the derivative spectroscopy, i. e. the first or second derivative of the spectra is derived. This approach requires a complete spectrum, not given if only 8 or 16 measurement points are recorded.		
Max. scan width (belt width) of one measurement setup (spectrograph and measurement optics)	2 m	Not known	1,4 m
	Valuation: The LLA solution permits evaluation of shredded material > 6,2 mm with a single measurement setup at a band width of 2 m.		
Colour sensor	Optional component	Optional component	Optional component
	Valuation: The effort for the integration of a colour sensors is comparable for all competing setups		
Number of measurement tracks	Max. 320/ 192	Not known	Not known
Max scan rate (scans/s)	270/ 795	Not known	Not known
Number of measurements/ spectra per second	86.400/ 153.600	25.000	160.000
	Valuation: The number of measurements of the Manufacturer A solution is considerable below the number of the LLA solution. The information content of the measurements is defined above all by the number of measurement points in the wavelength band. The information content is for the manufacturer A and B solution considerable lower and for some important tasks therefore not sufficient.		

Component and characteristics	LLA KUSTA1.7MSI/ KUSTA1.9MSI	Manufacturer A	Manufacturer B
Number of measurement points in the wave length range per second	86.400 x 256 = 22.118.400 153.600 x 96 = 14.745.600	25.000 x 8 = 200.000	160.000 x 16 = 2.560.000
Digital resolution of the detector	14 bit/ 16 bit	Not known	Not known
Minimal track or measurement area at a detection width of 50 cm	0,16 cm x 0,26 cm/ 0,26 cm x 0,26 cm	1,0 cm x 1,0 cm	0,4 cm x 0,4 cm
Valuation: The LLA solution offers the highest spatial resolution.			
Analytical selectivity for identification of polymers	High	Average	Average
Analytical evaluation of waste paper, wood and minerals	Possible	Not possible	Limited
Adaptation to different sorting widths	Field of view of the camera may be adapted to width of conveyor belt.	Not known	Multiples of the width of the measurement setup are possible.
Adaptation to changed sorting task	Adaptation of the analysis routine within control software is possible.	Hardware changes may be required (setting of different wave lengths).	Hardware changes may be required (setting of different wave lengths).

3.1. Visualisation of sample identification / LLA Instruments GmbH

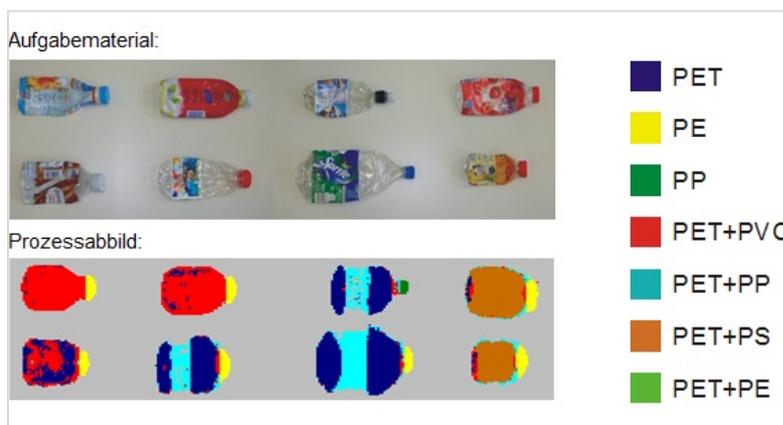


figure 5

Object identification and visualisation of bottles in the software KustaBelt

3.2. Comparison of applications

Sorting task	Dimensions	LLA	Manufacturer A	Manufacturer B
1 Domestic waste (packaging)	LLA: O: 2 – 40 mm M: 0,05 – 0,25 cm ² G: ≤ 3 m/s Manufacturer A: O: 30 – 350 mm M: ≤ 1 cm ² G: ≤ 3 m/s Manufacturer B: O: n/a M: n/a G: n/a	<i>Identification:</i> Packaging: PE-HD, PE-LD, PP, PET, PS, EPS, PVC, Tetra, labels Bottles: PET, PET-G, PVC, labels Foil: PE-HD, PE-LD, PP, PS, PVC, PET	<i>Identification:</i> PS, EPS, PP, Tetra, PE-HD, PET, PVC	<i>Identification:</i> PE, PVC, PET, PET-G, PP, PS, EPS
		<i>Impurities:</i> Paper, cardboard, wood	<i>Impurities:</i> Paper, cardboard	<i>Impurities:</i> Paper, cardboard, wood
2 Electronic plastics	LLA: O: 2 – 40 mm M: 0,05 – 0,25 cm ² G: ≤ 3 m/s	<i>Input material:</i> Chassis of waste electrical devices <i>Identification:</i> ABS, PS, PP, PA, PVC, PE, PET, PBT, PUR, PC, PMMA, PC+ABS, ABS+PVC, PPE+SB <i>Impurities:</i> Brominated flame retardants ABS+TBBPA, ABS+TBBPAepox, PS+TBBPA, PS+TBBPAepox	N/a	Not a pure NIR application, offered only in combination with x-ray technique.
3 Refuse derived fuel (RDF)	LLA: O: 2 – 40 mm M: 0,05 – 0,25 cm ² G: ≤ 3 m/s Manufacturer A: O: 10 – 350 mm M: ≤ 1 cm ² G: ≤ 3 m/s Manufacturer B: O: n/a M: n/a G: n/a	<i>Input material:</i> - Domestic waste - Construction waste <i>Identification:</i> - All plastic sorts - Wood, paper <i>Impurities:</i> - Chlorine containing compounds (PVC) - Plastics with halogenated additives (flame retardants)	<i>Input material:</i> Not further specified <i>Identification:</i> All fractions (not further specified) <i>Impurities:</i> PVC	<i>Input material:</i> Not further specified <i>Identification:</i> All plastic types <i>Impurities:</i> PVC

Sorting task	Dimensions	LLA	Manufacturer A	Manufacturer B
4 Car recycling	LLA: O: 2 – 40 mm M: 0,05 – 0,25 cm ² G: ≤ 3 m/s	<i>Identification:</i> Light plastics: ABS, PC, PP, PU, PE, PMMA, PA, PC+PBT, PC+ABS Black plastics: PP (PP+EPDM), PC (PC+PBT), PBT, PUR	N/a	Not a pure NIR application, offered only in combination with x-ray technique.
5 Carpet recycling	LLA: O: 2 – 40 mm M: 0,05 – 0,25 cm ² G: ≤ 2 m/s	<i>Identification:</i> PA6, PA66, Blend PA6+PA66, PP, PES, wool	N/a	N/a

Legend of abbreviations:

O: Object size

M: Size of measurement area

G: Speed of conveyor belt

N/a: Information not available

3.3. NIR spectroscopic evaluation of waste paper

Paper is an industrially manufactured product with the main components cellulose and lignin (groundwood pulp). As fillers respectively for the Papier strich in Europe predominantly kaolin and calcium carbonate are used. The waste paper - sorts are distinguished by the quantitative composition of these components. Because of this, the separation of waste paper by NIR is a very demanding sorting application. For the quantification of the components the NIR spectra need to have a high spectral resolution with low noise. Only if these two criteria are met, a mathematical processing (PLS, PCR) is possible. The figure 6 and figure 7 show spectra examples of three different waste papers.

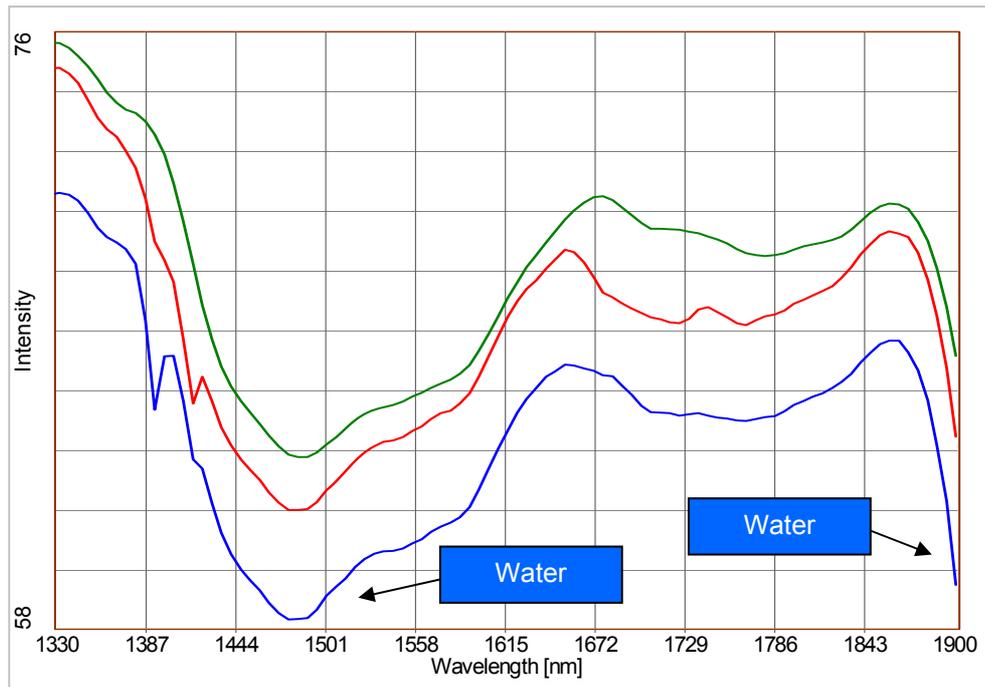


figure 6

Three paper spectra recorded with KUSTA1.9MSI with each 96 support points in the wavelength range of 1330 nm to 1900 nm (office paper, magazine, carrier board). The visible differences in the spectra curve are the result of the moisture contents of the samples. Different paper sorts may not be identified.

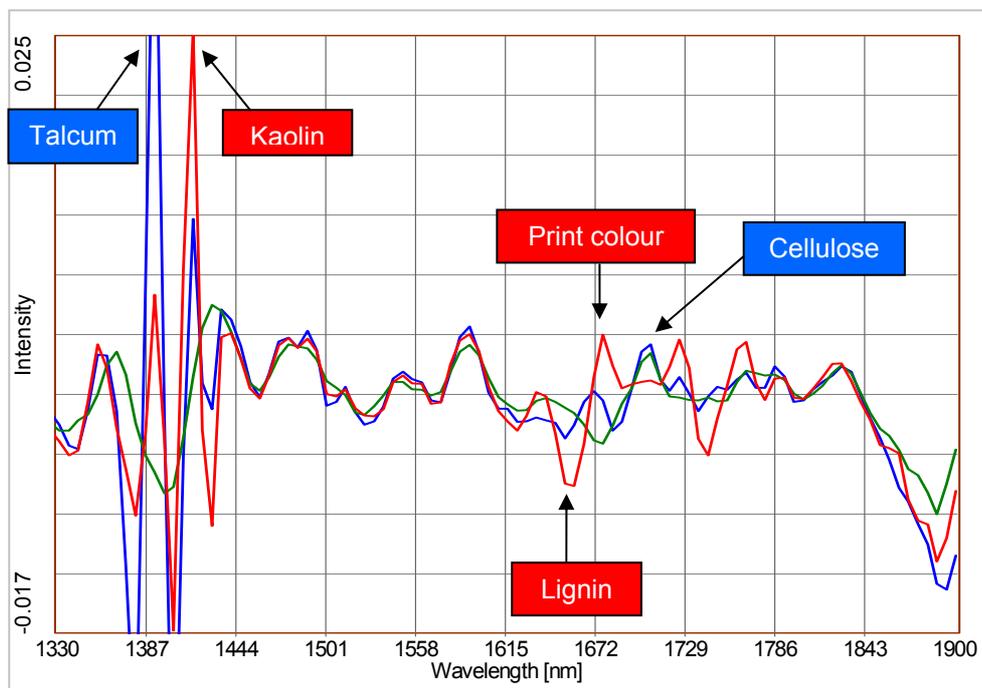


figure 7

Second mathematical derivative of figure 6 (office paper, magazine, carrier board). Based on the absorption bands of the different components may be determined and quantified. The extremely sharp peaks of the mineral pigments are clearly visible.

Compared to plastics paper has a high water contents. The identification of paper sorts by the untreated spectra is therefore not possible – the absorption bands of water are dominant. Looking at the spectra of figure 6 one observes that the water absorption bands are covering in a wide range the absorption bands of other components. The derivative spectroscopy presents a large advantage for the analysis. Here not the untreated spectra, but their mathematical derivative is used for further analysis. By that, the effects of interfering components in the spectra will be corrected, and systematic deviations of the basis line removed. In the second derivative of the spectra exists a proportional relation between absorption and concentration of components (see figure 7). There are prerequisites for the application of the derivative spectroscopy. NIR detectors with 32 or less sampling points in the wavelength range are not suitable for use in the derivative spectroscopy. Therefore the use of such NIR systems in waste paper identification is questionable.

3.4. Waste paper recycling

Sorting task	Dimensions	LLA	Manufacturer A	Manufacturer B
1 Paper and cardboard (qualitative)	LLA: O: > 100 mm M: 1 – 10 cm ² G: ≤ 3 m/s	Sorting according to EN 643 (group 1.11 deinking material)	- Brown or printed carrier boards and corrugated cardboard - Cardboard - Newspapers, magazines, printed paper - Tetra Pak	- Brown card board - Newspapers - Plastic coated cardboard - Coloured cardboard - Four colour print paper
	Manufacturer A: O: 30 – 300 mm M: ≤ 1 cm ² G: ≤ 3 m/s	- Print products (newspapers magazines, catalogues) - Office paper		
	Manufacturer B: O: 50 – 300 mm M: n/a G: n/a	<i>Impurities:</i> - Unwanted paper (brown- and corrugated cardboard, carrier boards, synthetic papers) - Coated products (plastic coated paper, Tetra Pak) - Plastics	<i>Impurities:</i> Plastics	<i>Impurities:</i> Plastics
2 Particular paper fractions (qualitative)	LLA: O: > 100 mm M: 1 – 10 cm ² G: ≤ 3 m/s	Print products manufactured on the basis of water based colours	N/a	N/a
	LLA: O: > 100 mm M: 1 – 10 cm ² G: ≤ 3 m/s	Print products manufactured on the basis of UV curing colours	N/a	N/a
3 Paper components (quantitative)	LLA: O: > 100 mm M: 1 – 10 cm ² G: ≤ 3 m/s	Determination of components (kaolin, CaCO ₃ , cellulose, lignin) mass percent	N/a	N/a
4 Water contents (quantitative)	LLA: O: > 100 mm M: 1 – 10 cm ² G: ≤ 3 m/s	Determination of paper moisture (mass percent)	N/a	N/a

Legend of abbreviations:

O: Object size

M: Size of measurement area

G: Speed of conveyor belt

N/a: Information not available

The specification list for deinking paper (group 1.11) according to EN 643 determines which waste paper is allowed to be transferred into deinking. All kinds of cardboard are unwanted paper products. The following table provides an overview of the impurity groups and their identification options in an industrial process.

Unwanted deinking paper groups		Identification with NIR	Identification with colour sensor
1	Brown cardboard, not laminated	Yes	Yes Good identification of homogeneous colour structures
2	Brown cardboard, paper laminated	Depends Depends on the thickness of the lamination	Depends Only if the cardboard is prior to identification slit and measured on the not covered inside.
3	All kinds of carrier boards	Yes Depending on the quality folded boxes are grouped in the standard groups GZ, GG, GC, GD, U.	No No differentiation criteria between folded boxes of solid board and newspapers, magazines, catalogues
4	Synthetic paper and plastic coated paper	Yes Good identification with NIR, because the plastic absorption bands are clearly detectable; mixed spectra paper/plastic	No
5	Differentiation of print products on the basis of flexo- and offset print	Yes Identification of the products by detection of significant colour components. During the measurement of the print products mixed spectra (paper und print colour) are obtained. The significant colour information is only detectable using derivative spectroscopy (2. mathematical derivative).	No
6	Solid coloured papers	Depends	Depends

LLA Instruments GmbH

Justus-von-Liebig-Str. 9/11
12489 Berlin

Phone: +49 (0) 30-6290790-0

Fax: +49 (0) 30-6290790-10

www.lla.de

www.lla-instruments.com

mail@lla.de