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Identification of Flexographic-printed Newspapers with NIR Spectral Imaging

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Abstract**—**Near-infrared (NIR) spectroscopy is a widely used method for material identification for laboratory and industrial applications. While standard spectrometers only allow measurements at one sampling point at a time, NIR Spectral Imaging techniques can measure, in real-time, both the size and shape of an object as well as identify the material the object is made of. The online classification and sorting of recovered paper with NIR Spectral Imaging (SI) is used with success in the paper recycling industry throughout Europe. Recently, the globalisation of the recycling material streams caused that water-based flexographic-printed newspapers mainly from UK and Italy appear also in central Europe. These flexo-printed newspapers are not sufficiently de-inkable with the standard de-inking process originally developed for offset-printed paper. This de-inking process removes the ink from recovered paper and is the fundamental processing step to produce high-quality paper from recovered paper. Thus, the flexo-printed newspapers are a growing problem for the recycling industry as they reduce the quality of the produced paper if their amount exceeds a certain limit within the recovered paper material.

This paper presents the results of a research project for the development of an automated entry inspection system for recovered paper that was jointly conducted by CTR AG (Austria) and PTS Papiertechnische Stiftung (Germany). Within the project an NIR SI prototype for the identification of flexo-printed newspaper has been developed. The prototype can identify and sort out flexo-printed newspapers in real-time and achieves a detection accuracy for flexo-printed newspaper of over 95%. NIR SI, the technology the prototype is based on, allows the development of inspection systems for incoming goods in a paper production facility as well as industrial sorting systems for recovered paper in the recycling industry in the near future.

Keywords**—**spectral imaging, imaging spectroscopy, NIR, water-based flexographic, flexo-printed, recovered paper, real-time classification.

I. INTRODUCTION

Recovered paper has become an important resource in the paper production industry. The amount of recovered paper required by the German paper factories was 15.2 mio. tons in 2006 and increased by by 830.000 tons relative to 2005 [1]. Before the paper factories can use the recovered paper it has to be improved by removing non-paper components like wood, polymers, metals and textiles from the material stream. Not enough, also card boards, corrugated boards, folding boxes and particular special papers (e.g. papers coated with polymers) have to be removed. So far, this is done successfully with optical sorting machines combined with manual sorting all over Europe.

However, recently another problem appeared: The globalisation of the recycling material streams caused that more and more water-based flexographic-printed newspapers from mainly UK and Italy appear also in central Europe. These flexo-printed newspapers are problematic because they are not de-inkable with the standard de-inking process for offset printed paper. The standard de-inking process removes the ink of offset-printed paper and is the fundamental processing step to produce high-quality paper from recovered paper. Although de-inkable flexo inks are under development, these inks are currently not commercially available. Thus, the current state, especially for the paper recycling industry is, that flexo-printed newspapers are not de-inkable with the standard de-inking process. They contaminate the produced paper and degrade its quality, if their amount exceeds a certain limit. With existing optical sorting equipment it was up to now not possible to identify flexo-printed newspapers in real-time. Visually, offset and flexo-printed newspapers are hardly distinguishable. Even experts can separate them only by using the newspaper titles or with a magnifying glass - a time consuming task. Fig. 1 shows some samples of flexo-printed and offset-printed newspapers. This paper presents the online classification results obtained with an NIR SI prototype of an optical sorting machine that is able to identify flexo-printed newspapers under controlled conditions with a high accuracy. The prototype is the first SI system that extends the wavelength range of NIR SI based sorting machines to 2500nm and increases the optical resolution so that a real-time flexo-ink detection becomes possible.

The developed SI prototype was designed to inspect consignments of recovered paper. The SI prototype uses an NIR hyperspectral imaging system and chemometric classification algorithms to identify unwanted items from a batch of recovered paper. An additional colour camera acquires images of the objects in the recovered paper batch. Both cameras scan the items while a conveyor belt inside the prototype moves the items from the throw-in opening to the ejection mechanism. Unwanted items are identified by the classification algorithms by their characteristic NIR spectra and are ejected from the conveyor belt by a pneumatic ejection mechanism.

The identification of flexo-printed newspapers and the sorting of recovered paper generally are not the only applications of spectral imaging. SI systems have been used in a number of other applications with success, showing the applicability for material classification and inspection. However, real-time requirements, which are of key importance for industrial applications, have been taken into account only rarely. Examples for other SI applications can be found in e.g. (i) the food industry for fruit quality and ripeness control during and after harvesting [16], [12] or for the detection of contamination

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Fig. 1. Visually flexo-printed newspapers (top) and offset-printed newspapers (bottom) are hardly distinguishable. Even experts can identify flexo-printed only by the newspaper title (e.g. Daily Mail, Il Gazzetino) or a magnifying glass. NIR spectral imaging identifes flexo-printed newspapers in real-time and thus enables the development of industrial sorting systems.

on poultry [10], (ii) for general colour measurements [13], or (iii) for geological and mineralogical applications, e.g. the discrimination of natural and artificial turquoises [6].

In the next section the related work is described briefly. In section III and IV the prototype and the chemometric methods are discussed and the results are presented in section V. The conclusions are drawn in section VI.

II. Related Work

Spectral Imaging (SI) is the combination of spectroscopy with digital image processing [7], [8]. While the images acquired by conventional colour cameras provide only the intensity of three colour channels (e.g. RGB) for each pixel, SI systems measure the full spectral information for each pixel in a selected wavelength range. There are three acquisition principles used in SI systems:

The first approach is the *wavelength scanning* principle: Single images of the sample are recorded for each measured wavelength. The spectral selection is achieved by (i) a number of discrete filters in a filter wheel [20], (ii) a tuneable filter [14] or (iii) an imaging Fourier-transform spectrometer [21], [17]. The images recorded for the different wavelengths are combined in the computer into a *spectral cube* with one spectral and two spatial dimensions. Using this *spectral cube* the spectrum of each pixel of the measured objects is available. Disadvantage of the *wavelength scanning* principle is that it is, except if a fast tuneable filter is used, slow and only applicable for static or stop-motion samples. For moving samples the spectral information gets corrupted because the subsequently acquired images of different wavelengths are no longer congruent. This acquisition principle is preferrable for SI applications realised with microscopes and static samples or for other offline analysis and inspection tasks.

The second approach, *spatial scanning*, requires a relative movement between the SI system and the sample. The SI system records the spatial information line by line. The spectrum of each pixel along the acquired line of the sample is spectrally dispersed giving a two-dimensional image that is projected onto a two-dimensional sensor array. One axis of the sensor array coincides with the spatial direction of the acquired line, while the second axis of the sensor array is related to the spectral dimension. I.e. the rows of the sensor array contain the intensity of the acquired line for the different wavelengths and the columns contain the spectrum of each pixel of the acquired line (or vice versa if the sensor array is rotated by 90°). The spectral dispersion is provided either by linearly variable filters [22] or by dispersive optics forming an imaging spectrograph [19]. A computer combines the slices to a spectral cube allowing the access to both the spatial and spectral information. SI systems based on imaging spectrograph are the most suitable approach for industrial applications and inspection tasks with moving samples. The common implementation is based on imaging spectrographs that are available for a variety of wavelength ranges from UV to IR.

The third approach comprises the so called *snapshot* SI systems that acquire the spatial and spectral information with a single camera frame. Examples of snapshot SI systems are the IRIS (image replicating imaging spectrometer) system that uses a lenslet array to project six images of different wavelengths onto a sensor array [3], or the CTIS (computed tomography imaging spectrometer) system that uses a holographic grating to acquire multispectral data in one camera frame [2].

For this industrial application, the identification of paper materials and printing inks, the *spatial scanning* principle is the most suitable one. The material is moved using a conveyor belt, thus the necessary movement between SI system and sample is already realised. Fig. 2 shows the basic components of such an industrial NIR SI system as NIR camera, imaging spectrograph, lens, illumination and transportation system. The NIR wavelength range, in particular the range from 1000nm to 2500nm provides sufficient material specific information - due to overtone and combination vibrational absorption bands of the major paper components - to apply chemometric algorithms for a identification of paper materials and printing inks.

III. Prototype

To allow the acquisition of reference sets with more than 100 samples and - after the development of the identification models - also an validation of the method with statistically meaningful sample sizes, a prototype of an NIR SI system for the inspection and sorting of material batches of up to 30kg has been developed. Fig. 3 shows the functional iagram of the developed prototype. The objects of the material batch (or the reference and validation sets) are put onto the conveyor belt using the manual material input opening. The objects are moved on the conveyor belt beneath the NIR SI acquisition system and the illumination. The SI system acquires the

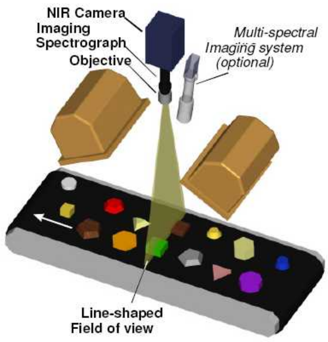

Fig. 2. Principle of an industrial NIR SI system using the *spatial scanning* acquisition principle. The SI system consists of NIR camera, imaging spectrograph, lens, illumination and material transportation.

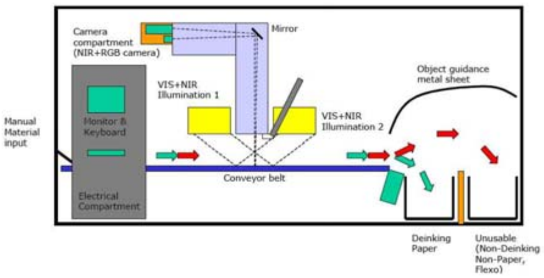

Fig. 3. Functional diagram of the protoype.

Fig. 4. The NIR SI protoype developed during the research project.

multispectral NIR images of the objects and analyses the spectra using chemometric material identification models. If an unwanted object is identified, it is ejected pneumatically into the second box. The wanted de-inkable papers are not ejected and fall into the first box.

High-quality NIR lenses (1000-2500nm) are not available in the same variety of focal lengths as lenses for visible light. Thus, the optical path of the acquisition system has to be folded using a mirror to acquire the entire width of the conveyor belt and still keep the height of the system under 2 metres and allowing the prototype to be moved through wide but standard-height doors. The prototype acquires NIR SI data and RGB images of the samples using an auxiliary colour line-scan camera for a live display of the objects and the classification result on the monitor.

The research prototype developed in this project is able to acquire training data, execute the online classification and eject unwanted objects from the material batch of recovered paper put onto the conveyor belt. Since it should be working also in an industrial environment, the prototype is embedded into a rugged steel frame and metal sheeting. Fig. 4 shows an digital image of the prototype.

The raw data acquired by the prototype can not be used directly for a training of chemometric algorithms and not for a multi-spectral classification. A pre-processing has to correct the spatial inhomogenities of the illumination, the spectrograph and the variation in the sensitivity of the camera pixels. In contrast to CCD or CMOS cameras the cooled MCT camera used to acquire the intensity of the NIR light exhibits a considerable variation in sensitivity between single pixels. The calibration is done by acquiring a dark image with closed lens and a white reference made of Titanium dioxide. These two images are used for a two-point calibration for each camera pixel. After this calibration, the reflectance images that can be used for the development of the identification model and - after the model development - for the online classification. Thus, this reflectance computation based on the two calibration images has to be carried out in real-time by the prototype. Throughout this paper only reflectance data were used.

IV. Methods

As near-infrared (NIR) light passes through a material it is selectively absorbed by molecules. The molecules of a given chemical compound vibrate with a characteristic set of frequencies or wavelengths. A photon can excite a molecule, and will be absorbed, only if the photon's wavelength is in the correct range.

NIR spectroscopy (1000 - 2500nm) observes the wavelengths of light that are absorbed and infers the types of molecules - the material - by using this information. By measuring the NIR spectra of a sample it is possible to infer its chemical composition. This allows objects to be sorted according to the material of which they are made of. In this way unusable objects, i.e. those not composed of the correct type of paper, can be identified and removed. Fig. 5 shows a typical NIR spectrum of a paper (magazine) with the indication of characteristic absorption bands of different paper components.

The vital information for chemometric identification algorithms are not only characteristic absorption bands, but also the slopes of the absorptions bands and subtle features not always visible to the eye when considering reflectance spectra. By the calculation of first or second derivatives these features can be emphasised and the results of the identification algorithms are usually improved. However, the derivatives have to be computed with care as spectra contain a considerable amount of noise that is amplified by derivative calculations. This can

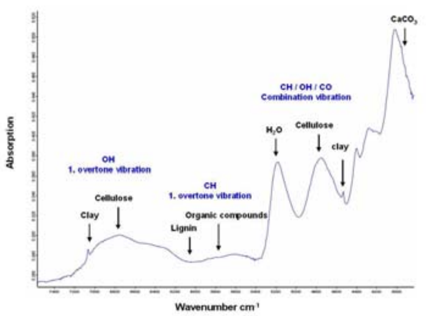

Fig. 5. NIR spectrum of a magazine and characteristic absorption bands of the different paper components.

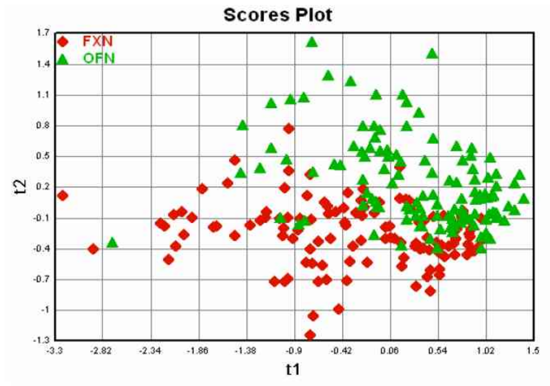

Fig. 7. 2D scatter plot of weights for the first two principal components of flexo- and offset printed newspaper.

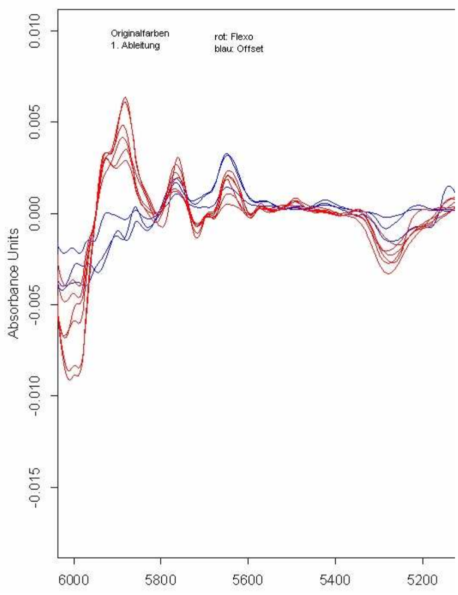

Fig. 6. First derivative of reflectance spectra of flexo and offset printed newspaper computed with the Savitzky-Golay approach.

be avoided by a smoothing of the spectra prior to differentiation or by using robust algorithms for the estimation of the derivative as Savitzky-Golay. We used the latter approach that fits a polynomial to a number of sampling points of the spectra and estimates the derivative from the fitted polynomial. If more sampling points are used as would be necessary to exactly calculate the polynomial the estimate gets more robust. This behaves as an implicit smoothing but gives better results as an e.g. Gaussian smoothing. The best results were obtained with the first derivative, cubic polynomial and 5 sampling points. This settings were used for all results presented in this paper. Fig. 6 shows the first derivative of some reflectance spectra of flexo and offset printed newspaper computed using the mentioned Savitzky-Golay approach.

Spectra and consequently also the first derivative of reflectance spectra are generally highly correlated. We applied a Principal Components Analysis (PCA) to reduce the dimensionality of the data before a Discriminant Partial Least Squares (PLS) regression model was used to classify the spectra. Each spectrum is described as a linear combination of the determined principal components. Fig. 7 shows a scatter plot of some spectra of flexo- and offset-printed newspaper. The coordinates are the weights for the first two principal components. In this co-ordinate system the samples fall into two clusters, which correspond with the spectra of flexo- and offset-printed newspapers. Using only two principal components, there is a considerable overlap between the two clusters as can be seen in Fig. 7. However, if more principal components are used the separation gets better as the classification results will show later on.

Subsequently to PCA, the weights (loadings) of each principal component are used for the PLS algorithm. The PLS regression determines a set of coefficients to classify a spectrum according to its weights for the chosen principal components. The paper categories used for the development of the identification model using PCA and PLS and the number of samples in the reference sets are listed in Tab. I. It turned out that a single PLS model is not sufficient for a solution of the task, hence the classification was split into several two-class sub-tasks. For each of the sub-tasks an own PLS model has been developed. The necessary PLS models were:

1) Paper vs. non-paper material
2) Paper vs. paper with plastics or textiles
3) De-inkable paper vs. non-de-inkable paper
4) De-inkable paper vs. flexo-printed newspaper

The sub-tasks were executed subsequently, meaning if a spectrum is not identified as non-paper by PLS model 1), it is analysed by PLS model 2) whether it is paper with plastics or textiles or not. If not PLS model 3) separates de-inkable paper from non-deinkable paper and if the spectrum is a de-inkable paper the final check by PLS model 4) is done wether it is a flexo-printed newspaper or not.

The consequence of the decision tree using the four PLS models is that the time to classify a spectrum depends on the classification result. I.e. the decision for a non-paper spectrum

TABLE I
THE CATEGORIES OF THE REFERENCE AND VALIDATION SETS OF THE SAMPLE MATERIAL

Description	Sample	Reference samples	Validation samples
Non-de-inkable paper and board			
Flexo-printed newspaper	FX	120	145
Card board	FSG, FSB, FSW, FSWB, FSWS	250	320
Corrugated board	WPB, WPSB, WPSW	190	220
De-inkable paper			
Offset-printed newspaper	OF	80	185
Newspaper	ZN	135	264
Magazine	MN	116	193
Magazine (glossy)	MNS	-	99
Brochures, flyer	FN	122	300
Brochues (glossy)	FNS	-	100
Catalogues	KAT	10	24
Office paper	BP	31	58
Non-paper components			
Plastics, polymers	K	44	64
Textiles	TEX	11	13

requires a shorter time than the decision to identify it as being from a flexo-printed newspaper. Despite this complication the optimised online implementation of the classification model was able to process and classify the data of each camera frame (a pixel line at the conveyor belt) always in less than 10 ms. Thus it was possible to analyse each frame and no frame drops occurred.

V. RESULTS

The entire identification model has been validated first using offline data of the validation samples, then the optimised online implementation of the entire identification model has been validated using the offline data. The second validation step unveiled a semantic error in the online implementation, but after it was fixed both the offline and online implementation of the classification gave the same results.

Subsequently to these validation steps, the entire model has been tested using the validation samples to evaluate the recognition performance of the model in real-time and the ejection efficiency of the prototype. The samples of the validation set were put on the conveyor belt of the prototype. The category shown on the display was used to determine the real-time classification decision of the entire identification model.

A. Recognition Performance

The main goal of the prototype was to demonstrate the recognition of flexo-printed newspapers in real-time. This was achieved with a recognition performance of over 95%. For the de-inkable paper and the non-paper categories (plastics, wood, textiles) recognition rates of over 90% were achieved. The large group of non-deinkable paper is difficult due to its large spectral variation. This influences the recognition performance for this group and the prototype achieved 70% to 90%. Vital for the achieved recognition performance of 95% for the flexo-printed newspapers is the high spatial resolution of the prototype and that multispectral image data can be acquired

TABLE II
THE RESULTS OF THE RECOGNITION PERFORMANCE FOR EACH CATEGORY.

Category	Samples	correct	wrong	performance
FX	145	142	3	97.9%
OF	185	152	33	82.2%
BP	96	92	4	95.8%
FN	10	8	2	80.0%
FNS	10	9	1	90.0%
KAT	10	10	0	100.0%
MN	99	98	1	99.0%
MNS	99	91	8	91.9%
ZN	261	261	0	100.0%
WPB	106	104	2	98.1%
WPSB	95	53	42	55.8%
WPSW	8	6	2	75.0%
FSG	126	99	27	78.6%
FSB	13	8	5	61.5%
FSW	10	6	4	60.0%
FSWB	108	57	51	52.8%
FSWS	10	6	4	60.0%

for a spectral range up to 2500nm. Combining all results for the evaluated categories together provides a recognition performance that has not been reached with optical inspection technologies before.

B. Sorting Efficiency

Material batches with items of size 10x10mm and 15x15mm have been prepared by UPM Kymmene to evaluate the ejection rate of the prototype for different sample sizes. The material samples consisted of two sets of approx. 20 objects, one with folded and corrugated boards and one with newspaper samples. The board samples were tested in four runs and the newspaper samples in two runs (after the second run the newspaper samples were almost completely destroyed by the pressure of the ejection air). For each run the detected objects and the successfully ejected objects have been counted.

The ejection rate is the probability that an object that has been detected correctyl is successfully ejected by the prototype. The tests showed that the average ejection rate is 86% for the 10x10cm objects and 95% for the 15x15cm objects. Although all objects were hit correctly near the centre of gravity, occasionally the object starts an unpredictable rotation. This unwanted, but unavoidable, rotation is the reason that some of the objects were hit but not properly ejected.

VI. CONCLUSION

The results presented in this paper show that the identification of the different material categories and especially of flexo-printed newspaper is feasible in real-time with the developed NIR SI prototype. The prototype is able to identify water-based flexographic-printed newspaper in real-time on a conveyor belt and eject the unwanted objects in order to ensure a high quality material stream of recovered paper. Consequently, this prototype can be used as a functional basis for the development of an industrial inspection system or an industrial sorting system for recovered paper. Such a system would help ensuring the quality criteria of recovered paper directly and indirectly also of the paper produced from recovered paper - currently almost any paper. The quality evaluation of recovered paper is still an important issue for the paper industry. Rising prices and the growing demand for recovered paper on the world market will make it even more desirable to develop new methods and devices to measure the quality, ensure the given quality level and guarantee the recyclability of recovered paper. Thus, these developments are of great interest for the paper production and paper recycling industry.

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Susanne Rosskopf studied wood sciences at the University of Hamburg and graduated 2003. After her studies she became a researcher at the RCF Paper Research Center of UPM-Kymmene Papier GmbH & Co. KG, Augsburg. She focused to the improvement of paper recyclability especially for innovative printing technology. One of the main topics is the development of NIR spectroscopy for identification of recovered paper grades. In this context she was the project speaker of the multi-client INGEDE project together with CTR AG. In 2007 Susanne Rosskopf got the Zellcheming award for young and outstanding researcher. In the beginning of 2008 she has been appointed as project manager for RCF recyclability and RCF quality management..