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Improved fault detection for inline optical inspections by evaluation of NIR images

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Abstract Industrial image processing is a widespread technology to evaluate the quality of work pieces. Major advantages of this technology are its contact-free mode of operation, fast evaluation times and moderate system costs. Usually the visible part of the light spectrum is used to discriminate between good and bad work pieces. However, in several applications a combination or even a substitution with the near infrared (NIR) part of the spectrum advances the evaluation. In this paper, several real world applications are presented and the achieved improvements are summarized by showing qualitative and quantitative results.

1 Introduction

Industrial image processing in the visible spectrum has a long and successful history. One reason for the success is the imitation of human perception. Inspection tasks that otherwise would be done manually are implemented in an automatic, continuously running mode. Thereby, the influence of the human factor (e.g. exhaustion) on the classification accuracy is highly reduced. Moreover, the availability of camera chips based on silicon enables cost-effective inspection systems.

Image processing is not limited to the visible range. Advanced cost-intensive detector materials (InGaAs, InSb) allow data acquisition up to 5 μm (wavelength) and more. In combination with optics for spectroscopic imaging, a detailed characterization of surfaces is feasible [1].

Additional insight on surface properties, however, could already be achieved with moderate costs and efforts. When applying silicon based sensor chips, the available spectral information extends up to 1000 nm (and more, depending on the noise level of the chip). Commercial off-the-shelf cameras allow the simultaneous data acquisition for imaging in the visible (VIS) and near infrared (NIR) range. In several applications, the additional information improves the contrast and facilitates the discrimination between good and bad parts (see e.g. [2,3] on hyperspectral imaging applications).

In this paper, real world applications from the field of industrial inline quality inspections are presented.

2 Approach

2.1 Combined image acquisition in VIS and NIR ranges

The demonstration of improved image quality (when switching from the visible spectrum to the near infrared spectrum) requires images from the same scene in different spectral ranges. An efficient way to acquire these images is to use multichannel cameras. For the image acquisition tasks in this paper, the camera JAI AD-080 CL was employed. Its key components are two silicon chips and a wavelength sensitive prism (see Fig. 5.1). In this way two images (with a one-to-one pixel correspondence) are acquired, the first one in the range from approx. 400 – 700 nm (VIS), the second one in the range of approx. 700 – 1000 nm (NIR). The image resolution is 1024×768 pixels with a frame rate of 30 Hz. Depending on the requirements of inspection tasks, other multichannel cameras by JAI or other manufacturers could be used as well.

2.2 Dye-based contrast enhancement in the NIR range

Dyes are typically tailored for their intended impact on the human eye. As a result, the spectral properties of the dyes are well defined in the visible range. In the NIR range, the properties are usually of less interest (for the dye manufacturers and product designers) and therefore only rarely described. In many real world applications, dyes are often not or only slightly absorbing in the NIR range which reveals the optical properties of the substrate in captured images. For several inspection tasks this effect could be used to improve the image contrast by performing the inspection in the NIR range (instead of the VIS range). The benefit of this approach will be demonstrated in the subsequent chapters.

More rarely, dyes are jointly optimized for the VIS and NIR range. This class of dyes is exemplified by the dye "Paliogen Black L 0086" from BASF: It has been designed for surfaces that require a dark black impression in the visible range. On the other hand, the surfaces should not overheat when exposed to bright sunlight. The reflectivity of the dye is shown in Fig. 5.1. The low reflectivity in the visible range hinders surface inspection such as detection of scratches, holes, etc. In this case, an evaluation of NIR images leads to more accurate and robust results.

2.3 Quantification of detection capability for surface flaws

In the subsequent chapters different fault detection applications will be shown. The detection will be done in the VIS and NIR range. In order to quantify the improvement, a defect signal to background signal ratio (DBR) will be calculated based on the standard signal to noise ratio (SNR) in optical inspection:

$$\mathrm{DBR} = \frac{E_D(I) - E_{BG}(I)}{\sigma_{BG}(I)} \tag{5.1}$$

The difference between the average defect intensity $E_D(I)$ and the average intensity of the background structure $E_{BG}(I)$ is calculated in the numerator. The denominator $\sigma_{BG}(I)$ contains the standard deviation of the background structure. The capability for detecting flaws depends on many factors, mainly on the statistics of the background structure (incl.

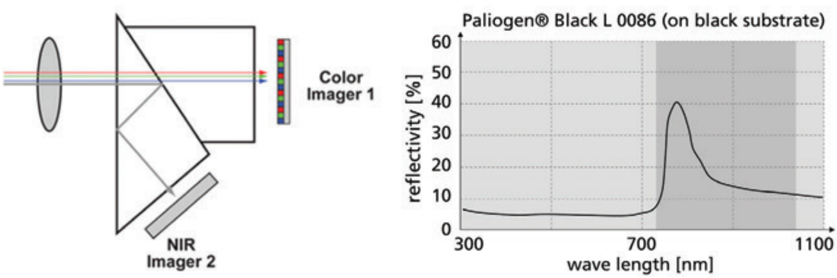

Figure 5.1: Optical path for the 2-CCD-camera JAI AD-080 CL [4] (left). Reflectivity of Paliogen Black L 0086, based on [5] (right).

spatial correlations) and the evaluation algorithms. However, higher DBR values usually indicate a higher probability for detecting flaws.

3 Application: Inspection of dyed polyester fabrics

Fault detection in polyester fabrics has several objectives: A key aspect is the identification of grease based contaminations, but also scratches and different foreign objects should be identified. The inspection task is especially difficult for black polyester fabrics: The contrast between unaffected fabric and grease based contaminations is very low. In this case, it is useful to switch to the NIR range. There are two reasons for this approach: (1) Polyester is highly transparent in the NIR range and (2) polyester dyes are usually optimized for the visible spectrum.

This is illustrated in Fig. 5.2: In the left image, the scratch and the contamination (red arrows) are nearly invisible on the black polyester fabric. The same scene recorded in the NIR range, however, shows excellent contrast: The DBR value increases from 0.7 to 30.3 (for the scratch) and from 2.1 to 19.7 (for the contamination). For the polyester fabrics, the flaws are already detectable by simple thresholding methods in the NIR range. Please note that a white layer was placed behind the fabric which reflects the illumination in the NIR range (originating from next to the camera). By a combined evaluation of both VIS and NIR images the probability of detection is highly improved when compared the VIS range only.

Moreover, as polyester is transparent in the NIR range, one could also detect flaws on the carrier or other subsurface structures when required (see Fig. 5.3).

4 Application: Detection of misssing threads in textiles

Flaw detection in woven material is a key task in textile industry. Fig. 5.4 shows a typical example for a missing thread that has to be identified during production. The inspection task is complicated by the existence of yarns in different colors, at least when evaluating images in the visible spectrum. An image in the NIR range from 700 – 1000 nm, however, reveals that the different dyes are only active in the visible range. In

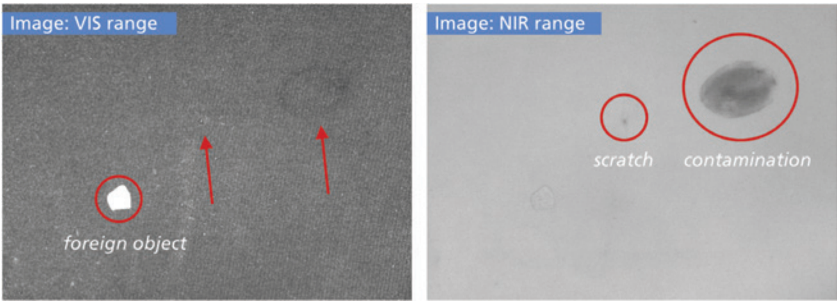

Figure 5.2: Quality inspection for a black polyester fabric using different spectral ranges. Only the combined evaluation of the VIS and NIR images reliably reveals all flaws.

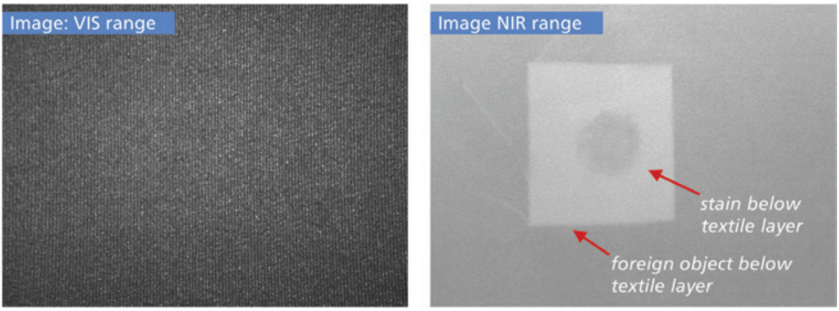

Figure 5.3: Subsurface inspection for black polyester fabrics. The left image was captured in the VIS range, the right image in the NIR range.

this case, using the NIR image decreases the contrast within the desired textile structures and increases the contrast of the faults.

The DBR value increases from 2.4 to 5.6 when switching from the VIS range to the NIR range. Depending on the detailed optical structure of the textile, the contrast may already be sufficient for thresholding algorithms. One may also apply more complex algorithms that reveal statistical anomalies in the image. As an example, Fig. 5.4 shows the evaluation results of the DefDetect algorithm [6]. Again the inspection task is highly facilitated in the NIR range.

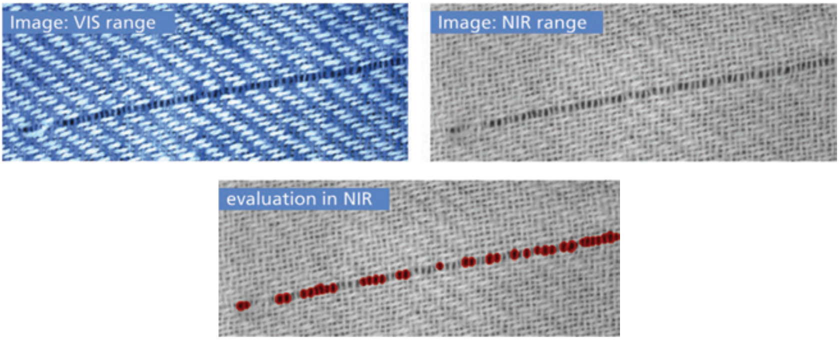

Figure 5.4: Missing thread in a woven material in the VIS and NIR range (top). Classification results based on statistical image analysis (bottom).

5 Application: Inspection of threads in textile seams

In textile industry, connecting different textile layers is usually done by making seams. The quality inspection of seams is rather difficult when the textile layers and the thread have similar colors. An example is shown in Fig. 5.5: Two sheets of black leather are interconnected by a black synthetic thread. In the VIS range, the contrast between the layers and the thread is relatively low. Inspecting the NIR image, however, is much easier as the black thread is highly reflective in this spectral range. The segmentation of the thread is easily done by thresholding methods and the regularity of the stitches is later evaluated by blob analysis methods. In this example, the DBR value increases from 3.5 to 5.5 when switching from the VIS range to the NIR range.

6 Application: Detection of surface contaminations on printed surfaces

Small surface contaminations (small particles or small patches of viscous fluids) are difficult to detect when they are located on printed surfaces with comparable colors. A good example is that of extruded window profiles covered with a wood imitating foil. Small particles from the production environment might be located directly on the foil which is undesirable for subsequent processing steps. In standard bright field

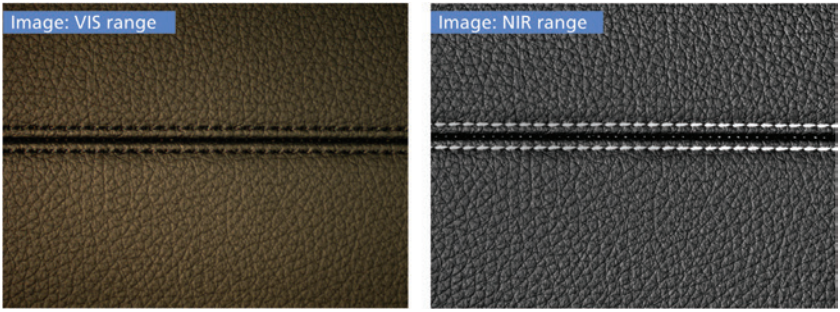

Figure 5.5: Black leather connected by black synthetic yarn. Low contrast in the VIS range (left), improved contrast in the NIR range (right).

illumination, see Fig. 5.6, the particles are hardly visible in the VIS range. Yet different other techniques from machine vision are available for detecting these kinds of particles: Dark field image acquisition typically reveals the defects although illumination needs additional efforts for big areas. The particles could also be detected by 3D imaging when their diameter is above the detection level of the imaging system.

Fig. 5.6 demonstrates that quality inspection is also feasible in bright field NIR imaging. On the left side, the image is shown in the visible range. It is difficult to identify the contaminations on top as they are constituted by small rusty iron fragments. On the right side, the image is shown in the NIR range. The different printing dyes are again optimized for the visible range showing only minimum NIR absorbance. The contaminations however are also highly absorbing in the NIR, leading to good contrast. In this application, the DBR value increases from 4.4 to 19.7 when switching from the VIS range to the NIR range.

7 Improvement of DBR values

The DBR values are a first indicator whether an inspection task is facilitated in the NIR range or not. The DBR values for the presented inspection tasks are summarized in Tab. 5.1. For these applications, the value typically increases by a factor 2 – 50 when switching to the NIR range. Assuming a Gaussion distribution for the background intensities, DBR

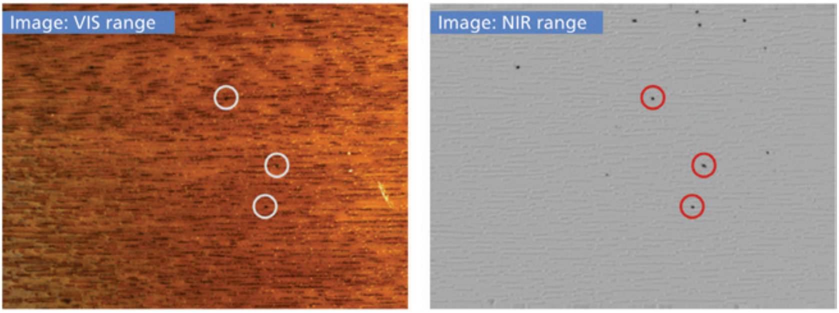

Figure 5.6: VIS and NIR image for a printed plastic foil covered with small metallic fragments, recorded in bright field illumination.

values greater than five should lead to good sensitivities/ specificities of subsequent binary classifiers. However, the requirement of a Gaussion distribution is seldom fullfilled in real word applications. Therefore, the final assessment of the improved detection capability requires the application of the full image processing chain.

Table 5.1: Summary on DBR values for the applications in this paper.

Inspection task	DBR value	
	VIS range	NIR range
Polyester fabrics inspection – scratch	0.7	30.3
Polyester fabrics inspection – contamination	2.1	19.7
Missing thread detection	2.4	5.6
Thread inspection in textile seams	3.5	5.5
Contamination detection on printed surfaces	4.4	19.7

8 Summary

Quality inspection tasks are usually performed in the visible spectrum imitating human inspection capabilities. It has been demonstrated for different applications that inspection tasks could be facilitated by switching from the VIS range to the NIR range. In this way one takes advantage that dyes are often not active in the NIR range. A noticable improvement of the image quality has already been achieved in the range from 700 nm – 1000 nm. Silicon based CCD camera chips could be used in this range which enables cost sensitive inspection solutions.

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