Keeping track of defects

Part 1: An introduction to »100% print inspection« and the technological status quo

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Automatic print inspection has become more and more sophisticated over the years. Originally, print inspection systems could only be used with a very limited number of applications and in most cases they had a negative influence on productivity. Software engineers tried their luck over time with complicated control algorithms. By now, the market has entered a consolidation phase. Specialized individual solutions have given way to system solutions, which meet the many different requirements of the label printers. The first chapter of this article describes the actual technological state. The focus is on promoting the understanding the technological limits set by the camera and lighting components available today. Part 2 will describe the practical use of print image inspection systems within the workflow.

What does 100% print inspection mean?

It is incorrect to believe that »100% print inspection« indicates that 100% of all defects will be detected all the time. Just like any other alarm raising monitoring system, print image inspection must work with threshold settings. The quality of defect detection also depends on the sensitivity setting within these threshold limits. The term »100% print image inspection« derives from the request to monitor the web continuously over the entire width and throughout the entire production process.

Of course a print inspection system will not detect defects for which it has not been designed. This can happen for example, if the defects are too small to be detected by the camera, or if the system sensitivity is set too low. Such a situation calls automatically for a systematic validation of the control result, an aspect which will be covered later. Unfortunately only the actual inspection result in form of labels found with defects can be valued.

Without further measures it cannot be said for sure whether:

- individual labels have eventually been skipped in the process,
- the actual thresholds are correct with respect to the quality specifications,
- the control algorithm will evaluate the threshold values differently resulting in a different defect determination.

The label printer expects all common defects to be found. Some of the most relevant defects have been compiled in *table 1*. How can these flaws be detected reliably?

Camera selection is crucial

The producer of an inspection system will opt for a particular camera type in view of the application to be served. As the performance and price spectrum of the various camera technologies presently available is very broad, we will elaborate on their major differences. The diagram in *figure 1* shows the opposing decision influencing features.

Though originally most print inspection systems used area cameras, line cameras are the preferred choice today. There are many reasons for this, one being that line cameras have a much higher resolution. Currently on the market are inspection systems based on line cameras with a pixel resolution of over 6000. Presuming that the image being acquired is a square this corresponds to a size of 36 megapixels. Whether such a high resolution is necessary or not will be discussed later. Standard area cameras on the other hand have up to 4 megapixels. Line cameras scan an image line by line, as the camera name implies. Therefore, there is no limitation with respect to the image length in the web running direction. With area cameras, on the other

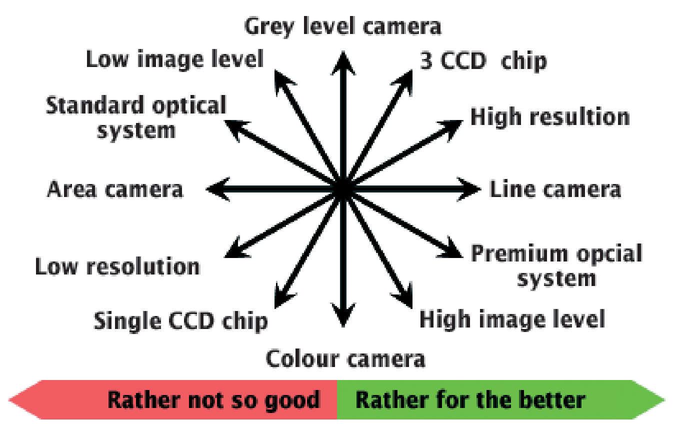

Figure 1:* *Opposed decision criteria for camera selection.

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hand, the inspection size is rigid and fixed in both directions. This produces serious limitations especially in web running direction. Furthermore, homogeneous illumination of a large area is considerably more difficult than lighting a narrow line. Area lighting requires much more space and the inspection area must be covered, in most cases, by a protective hood.

The next major decision factor is the use of a black and white camera or colour camera. Colour cameras still have, unfortunately, two considerable deficits in comparison to grayscale cameras, namely the resolution level and the image definition. On the other hand, a grayscale camera can only distinguish between the different levels of brightness and does not distinguish by colour. The inspection results are therefore rather ambiguous. Therefore the question as to which camera should be used can only be answered case by case depending on the application.

Grayscale cameras will be used with applications for which it is most important that small text elements or small graphic elements are correct and complete. Industrial and pharmaceutical labels are a typical example for the use of grayscale cameras.

Applications for which the quality of reproduction is crucial will use colour cameras for inspection. Labels for cosmetic products and food packaging are typical examples for colour camera use. The many different types of colour cameras available differentiate themselves by their ability to achieve correct colour reproduction. One-chip cameras are the usual choice, they cost less, but have deficits in colour fidelity. Take orange shades for example, these are often displayed as red, and small colour variations are not resolved. Recently, however, three chip cameras with optical colour separation have been introduced to the market. Though these are much more expensive, their capacity for colour representation makes them a good choice.

Another important factor to be considered is the possible inspection speed. This depends to a very large extent on the type of camera used. With line scan cameras the speed is determined by the maximum line frequency of the camera. Grayscale cameras have a frequency of 20 kHz to 50 kHz. With one-chip colour cameras the frequency is below 10 kHz and with three-chip colour cameras it is about 20 kHz. The resolution in all cases is based on the number of pixels available in the camera and the covered web width (field of view). It is easy to calculate the amount of web per pixel (pixel size). Divide the web width by the number of pixels. Example: If the camera has 4000 pixels and if the web width is 400 mm (15.75"), the pixel size is 0.1 mm (0.004"). Presuming that the pixels are of even height in the direction of the running web (square pixel), the maximum inspection speed of a camera with 25 kHz line frequency and with the assumed web width will be calculated as follows:

$$
\begin{aligned}
V_{max} &= \text{line frequency (Hz) x pixel height (mm)/} \\
&\quad \text{1000 x 60} \\
&= \text{25,000 x 0.1/1000 x 60} \\
&= \text{150 m/min}
\end{aligned}
$$

This value is a definite limit for the given camera. The only way to extend this limit upwards is to increase the pixel height with respect to the pixel width, thus lengthening the image. This means that the resolution in the web running direction is reduced.

Lighting is critical

Modern label printers have a wide variety of different materials and finishing processes at their disposal. Consequently, most finished labels are not just single or dual colour prints with clearly identifiable characteristics. Instead, they are a combination of different methods and materials such as hot foil, embossed films, transparent liners, silicon coated materials and others. These applications must be checked to select the right camera in combination with the right illumination method. Proper lighting is key to making these different features clearly and evenly visible for inspection and to reduce the risk of false defects.

High quality lighting depends, to a very large degree, not only on the light intensity but also the frequency of the spectrum and the illumination angle. The light intensity must be harmonized with the sensitivity of the camera. High demands are made today on this intensity in combination with high-resolution linescan cameras, and these can be met with highly efficient light sources. More important is the emitted light spectrum, which should preferably be white for colour sensitive applications. Metal vapour coated lamps and LED lights are doing a good job at this point. Another benefit of both is their long useful working life.

Another important factor is the angle and direction of illumination. The homogeneity of the image throughout the complete inspection procedure is critical for a meaningful inspection result. Special attention must be paid to the selected lighting with some particular features such as metal foil, holograms, embossing etc.

Directional light or diffused light

There are two basic lighting princi-

Missing letters/ parts of letters	Filled letters
Blurs	Register inaccuracies (flash-ups)
Spots and splashes	Register inaccuracies (punching edge)
Barcode	Colour variation

Table 1: A selection of different defects.

Figure 2: Print inspection system with directional light on a rewinder.

ples, which meet all these requirements. The first uses a directional light source, which means that light shines onto the web from a defined angle. If the camera is not mounted at the same angle of incidence as the light, the reflected metal surfaces will be dark but homogeneous. This type of lighting is suitable when checking for defects and for the presence of metal foils. If the camera is now turned into the direction of the light reflection axis of the directional light beam, a point of total reflection will be reached when the angles are the same. Once the camera angle is optimized, homogeneous foils as well as silicon coatings can be inspected. Controlled illumination is not the only benefit of this principle, a particularly favourable point is that the web is not subject to any kind of heating at the point where the light hits the web because the light is carried through fibre optics.

In addition to the lighting systems based on directional light, there are those using the so-called »dome light« principle. In this case the web is lit by diffused light, which comes from as many directions as possible. This is a shadow-free illumination, which is most suitable for lighting raised structures such as imprints. Generally speaking, the lighting is critical for many applications. Extensive lab tests should therefore be made with the given material before a project is formally started.

What defect sizes can be detected?

The choice of an inspection system is influenced by the detection capacity of the individual system, in other words by the smallest possible defect size that the system will detect reliably. As colour variations usually cover somewhat larger areas, they will not be dealt with in the following text. Only those defects, which result either from missing or from excessive coatings or deposits, will be addressed. Often the smallest detectable defect size is equated with the size of a camera pixel. This presumption is acceptable when inspecting homogeneous surfaces or homogeneous backgrounds. However, if the smallest possible defects are either close to or even within changing web areas such as letters, this definition is no longer applicable. For example, if a letter is slightly thick this deviation will be acceptable in most cases and should not create a defect message. The same applies to minor register fluctuations and to distortions due to changes in web tension occurring with flexible films. These defects too must be accepted by the inspection system and should not cause defect messages. Though modern inspection systems compensate for these defects through adaptive control algorithms, the quality of the print and the accuracy of the inspection process are still closely inter-related. It follows from these considerations that the smallest detectable defect is always a result of a certain number of pixels, which have been classified as defective. This number of pixels is the result of the print accuracy and amounts in practice to at least two or three pixels in every direction. The option to validate a certain minimum defect size is also important for critical applications. This means those defects, which are bigger than the minimum defect size will be detected for sure and not just by chance.

The impact of camera resolution is detailed in *figure 3*. The same letter »e« is shown with a resolution of 6000 pixels and of 2000 pixels. If

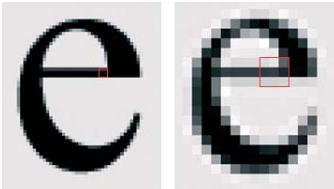

Figure 3:
Enlargement, left at 6000 pixel resolution right at 2000 pixel resolution.

Figure 4:
Validation features on the report.

Type of defect	Web width / Camera type	below 250 mm, below 10" Colour	Grey	250–300 mm, 10"–12" Colour	Grey	300–400 mm, 12"–16" Colour	Grey	400–550 mm, 16"–22" Colour	Grey
Large splashes and stains		●●●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●●●
Medium sized splashes and stains		●●●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●●	●●●●
Small splashes and stains		●●●	●●●●	●●●	●●●●	●●	●●●●	●	●●●●
Large-area colour deviations		●●●●	●●	●●●●	●●	●●●●	●●	●●●●	●●
Small colour deviation		●●●●	●●	●●●	●●	●●●	●●	●●	●●
Defects in print (above 10 points)		●●●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●●	●●●●
Defects in print (8–10 points)		●●●●	●●●●	●●●	●●●●	●●	●●●●	●	●●●●
Defects in print (5–7 points)		●●●	●●●●	●	●●●●		●●●		●●
Wrong imprints		●●●	●●●●	●	●●●●		●●●		●●

Table 2:
Decision matrix for colour camera versus grey level camera.

the horizontal line of the »e« was lost, the letter would look like a »c«. Remembering what has been said about the resolution it is now quite obvious that in this example an inspection system with a resolution of 2000 pixels would be at its limits.

Validating the inspection quality

When validating an inspection system it should be kept in mind that applications in pharmaceutical and security printing have their own special demands. The most important fact is that all actions of the operation can be traced back at any time by means of a reporting system as well as by means of security techniques.

We shall now discuss what can be done to validate the inspection quality. It is most unfortunate that in most cases the label printer is not aware of the quality defects and difficulties that might occur. A print inspection system is based on so-called positive logic. This means that as long as no defect is detected by the system, it is generally presumed that the material is ok and that it will be sent to the user defect-free. But what happens in the case where an operator decides to increase the system productivity and therefore reduces the threshold values, which have originally been determined by extensive tests? Inspection systems allowing threshold adjustments during operation are not immune to such actions. In the end the printer cannot be absolutely sure about the quality shipped to the user. There are stricter systems available, which allow threshold modifications only before the inspection starts. Moreover, thresholds are usually confirmed (validated) by testing. Strictly speaking, however, these values are not automatically adequate as built-in parameters such as the lighting might have changed.

There are two methods to get these elements of uncertainty under control. Either a test run is made at regular intervals with a roll prepared for this very purpose or the following trick is used which is available as a separate function with many print inspection systems:

A defect is intentionally applied somewhere on the printing plate within an unused area of a repeat. Subject to the number of repeats this defect will always be detected in the corresponding print provided that the quality requirements have been set accordingly. The inspection within this specific area can be activated for spontaneous validation after which it can again be deactivated. *Figure 4* shows how this concept can be achieved with labels. Validation is done by means of an additional and a missing line element. It is only reasonable to use a line thickness for the validation feature, which corresponds to the font used.

The second chapter of this article will be published in the next issue of this magazine. It will discuss »100% print image inspection« in the workflow of label printers. Equal attention will be paid to applications in the pre-press, press and finishing sections.

(*to be continued*)