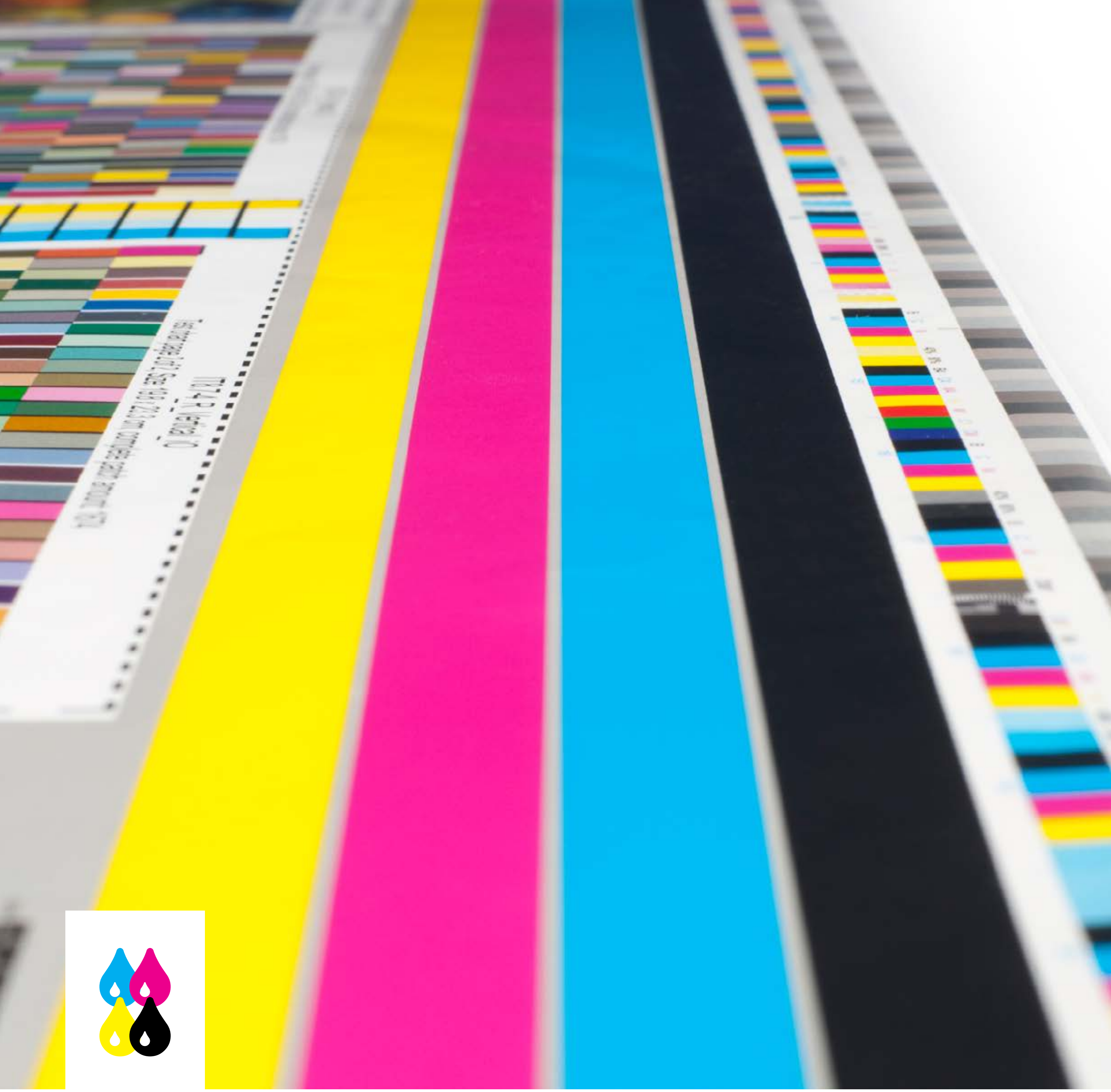


Ensuring a Perfect Image: The Challenges in Building a Better Print Inspection System

XIRIS
Inspection Solutions with Vision

Background

Whether it is printed using a pad, offset, screen or digital system, every product that comes off a printing machine needs to be perfect to meet the quality expectations of the modern customer.

Marketers put great effort into distinguishing their products from others with bold and exotic labeling techniques. Careful inspection of these labels is necessary to ensure the quality of the product and smooth operation of the printing process.

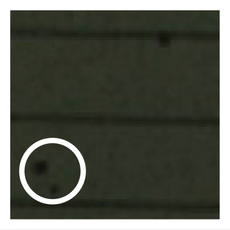
For each type of printing process, properly detecting all the printing defects in a printed image requires inspection, including the images included in the right sidebar of this document.

The best types of print inspection systems use intelligent inspection algorithms that mimic the human eye and brain to detect defects in the intricacies of the printed designs. This requires algorithms that can identify subtle color variations and a wide range of pattern defects in a printed region with the accuracy of close-range human inspection, all at standard production speeds. The process must also be advanced enough to adaptively allow small variations as a result of inaccuracies in the printing process to not cause a defect.

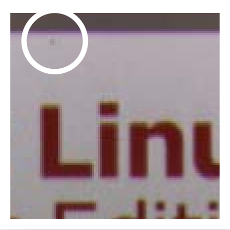
For a reliable print inspection to happen, the process requires a number of challenges to be solved correctly:

Common Printing Defects

Detection of insufficient/ excessive ink



Detection of blocked/ damaged ink jet nozzles



Detection of lacquer blemishes

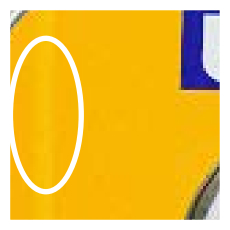
Challenge #1
Providing Suitable Illumination

The illumination for a print inspection system is usually a combination of high-technology light sources and custom-made optics. Since an image is only as good as its illumination, the illumination system must deliver good-quality, uniformly distributed lighting to the surface of the printed object—or the inspection process will not function. The system also must tolerate all possible surface finishes and ink types (e.g., highly reflective ink, non-reflective ink, very dark ink, very bright ink, highly reflective surfaces, low reflective/ matte surfaces, or polarizing substrate surfaces), all of which may be found within the same printed object. Often, print inspection systems use a combination of illumination sources to achieve this effect, including diffused and focused light sources that are on axis (collinear) or off axis (dark field illumination).

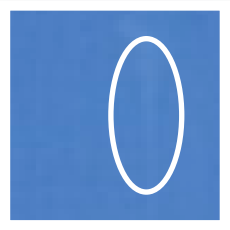
Each focused light source should be collimated (i.e., nearly parallel rays that spread slowly with distance) to provide the most accurate capture of light bouncing back from a reflective substrate.

Diffuse light sources with full spectral output are a basic requirement for print inspection, suitable for inspecting printed images of almost any color. The light must be diffuse enough so as to not provide any reflections or "hotspots" on

Detection of smudges

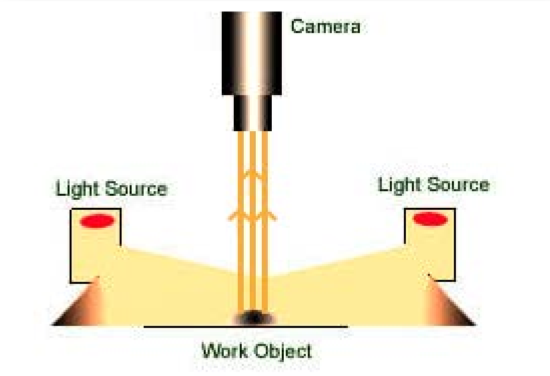


Detection of squeegee marks in a screen printing process.



Detection of print "ghosting" defects

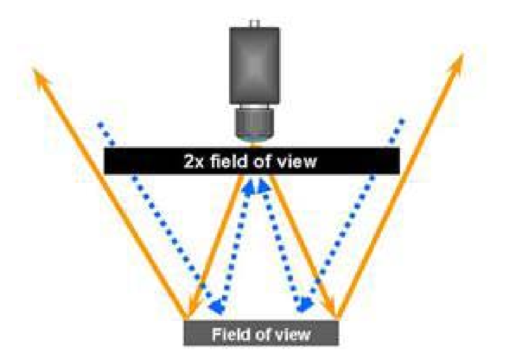
the substrate material, and it must be balanced across the printed object under inspection so that it provides a fairly consistent intensity level across the image.



Diffused light source

Courtesy – www.looptechnology.com

A collimated, collinear light source is a focused light source that runs down the same optical path that goes to the camera. When it is directly in the optical path, it provides “bright field” illumination to the camera, so that any print surface defects, such as scratches or highly reflective metallized regions, will be fully detected.



A bright field light source

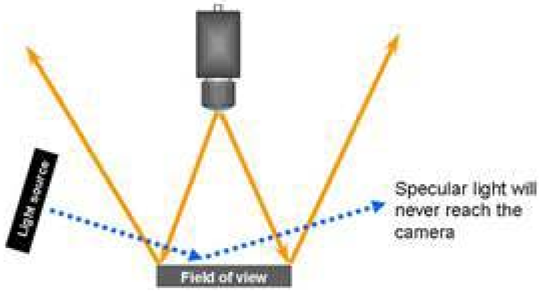
Courtesy – www.microscan.com

Character print quality recognition or verification

Detection of scratches

Detection of pinholes/ dirt

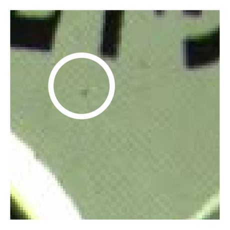
An off-axis light source that provides focused light but slightly off the axis of the camera's optics is useful in creating "dark field" illumination to the camera, so as to obtain high-contrast images to detect surface-related defects such as texture or surface scratches.



A dark field (off axis) light source

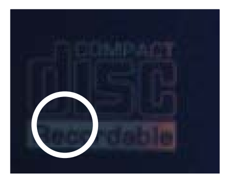
Courtesy – www.microscan.com

No matter what type of illumination is used, the light sources must be properly designed to provide the best possible spectral output, provide stable light intensity, and be easily switched by an external light controller. Such light sources are key to any inspection system, allowing it to properly present the features of the printed object under inspection.



Printed feature detection or verification

Bar code recognition or verification



Detection of substrate discoloration

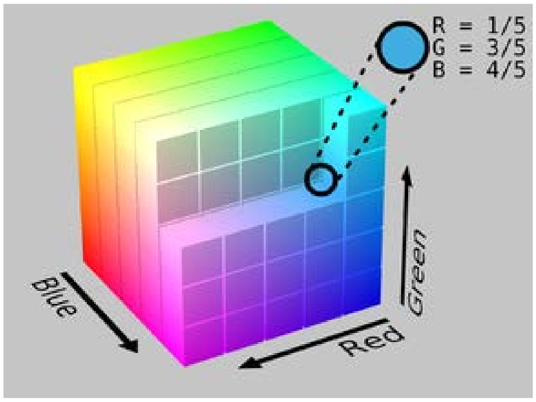
Challenge #2
Measuring Color

The detection of colored print by human beings is a difficult and subjective task. The human eye is capable of detecting very small shifts in color between two printed objects that are placed side by side. However, human perception of color varies so much from one individual to another that it is quite difficult to reliably analyze or verify one color sample to another. Not all people can see the same shifts in a particular color—some people are more sensitive to a specific color; others may not be as sensitive to the same amount of color shift observed by one inspector in one color. Also, the human eye perceives color non-linearly: for example, a red object will appear brighter than a blue object of the same intensity.

As a result, there are many instances where an objective image comparison process based on a standardized color measurement system needs to be used to provide a standard color verification process. Such a process must be modeled after the human eye to be able to properly detect small, subtle color shifts—but it must be measurable in such a way as to make objective comparisons possible.
When a color image is electronically captured and digitized in the controlled environment of print inspection, a color image can be processed to provide reliable, consistent results using true color image processing.

There are two issues that characterize color image processing:

- The color space. This is an abstract mathematical model describing the way colors can be represented as three or four sets of numbers, each of which represents a color component. It is used to code the color information so it can be stored and processed.

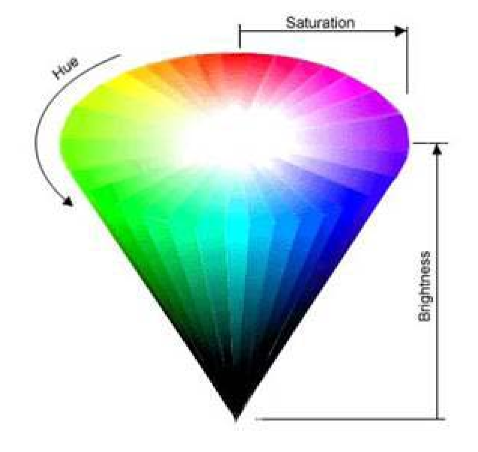


RGB Color Space

Courtesy – www.wikipedia.org

- The segmentation method. Color images acquired by a camera are typically acquired in the "RGB" (Red-Green-Blue) color space. In this case, each pixel is represented as a point in the RGB space. However, the problem is that the RGB space does not represent how the human eye perceives color. The human eye perceives color in a non-linear fashion, so a color space that mimics the human eye needs to be used for image processing to be able to detect subtle color defects in much the same way as a human eye can.

Some color spaces, such as "XYZ" and "I1I2I3" have been experimentally defined and are derived through linear transformation from the RGB color space. These spaces are close to human perception but not as effective as those color spaces that have been mathematically modeled to match human color perception, such as "HIS" (Hue-Intensity Saturation), "L*a*b" or "LUV". These color spaces are derived from a non-linear transformation of the RGB color space.



HIS color space

Courtesy – www.wikipedia.org

For proper print inspection, a non-linear color space such as HIS has to be used to measure differences in color. The challenge therefore is to acquire an image in RGB color space from standard video equipment and then accurately convert it to the non-linear color space as rapidly as possible before image comparison algorithms are implemented. Such conversions may require specific experimental or observational calibrations of key colors such as white points to achieve correct values.

Color measurement
– low saturated color

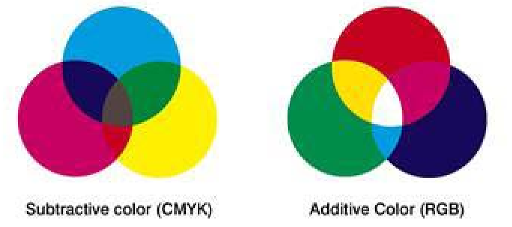
Color measurement
– high saturated color

Challenge #3

Converting Color Measurements to Machine Control

The non-linear color space (e.g., HIS) that is used to process the color variance in the pattern-matching process between a candidate image and the master image will not be easily understood by the operators of the printing machines. In the printing world, the main color space used is the "CMYK" (Cyan, Magenta, Yellow, Black) color space.

CMYK is a subtractive color space, meaning that a limited set of dyes, inks, or natural colors are mixed to create a wider range of colors, each of which is the result of partially or completely subtracting (that is, absorbing) some wavelengths of light. CMYK forms the basis of how printed color images are built and how printing systems are maintained, because it is a subtractive color. An operator, looking to control the color of a print, looks at adjusting any one of the CMYK ink levels to make it right.



CMYK vs. RGB

Courtesy — www.designtheplanet.com

To make a print inspection system more usable for the operator, the average color found in a region of the print should be reported to the operator in CMYK coordinates to allow the operator to correlate the color difference to real world printing dye or ink levels. The best print inspection design, therefore, requires a conversion from the internal color space used to measure the color on the printed object (such as the HIS space) to the CMYK values better understood by the operator.

A major complication is to convert from a 3-variable color space such as HIS to a 4-variable color space such as CMYK. This cannot be done accurately without "a priori" knowledge of the color separation process that was used to create the printing plates.

Challenge #4

Creating Print Variation Tolerance in the Inspection Algorithm

Print variations are all the differences between printed objects that should be alike because they were produced under similar printing conditions. In order to control a printing process, print variation must be measured and described. In any inspection process, there is usually a bimodal distribution of categories of detects: some features are always detected as non-defects correctly; whereas some features are always detected as defects correctly.

The problem is the category in-between—when some features that should be categorized as defects are found by a print inspection system to be acceptable (known as "false accepts") while other features that should be categorized as acceptable are found by a print inspection system to be defective (known as "false rejects"). The best types of print inspection systems will have enough intelligence in the inspection algorithm to minimize the amount of false accepts and false rejects and therefore improve the ability to tolerate some print variation without calling it a defect.

In print inspection there are always a number of "problem" print samples that are challenging to a print inspection system because under similar inspection conditions, they could generate different inspection results. Some examples include:

+ When the full dynamic range of a color is present from a near black to the brightest, saturated, almost reflective shade of the color.

+ Subtle surface defects such as minor scratches or print marks exist that cause localized printing variations.

+ Highly reflective or specular substrates appear in combination with patterns printed with highly reflective inks.

+ Highly reflective substrates that are only partially covered with print;

+ Substrates with clear or colored lacquers over a printed image.

By implementing the correct algorithms, a print inspection system can be more tolerant to a variety of print and substrate variations found in the market without causing undue false accepts or false rejects.

Challenge #5
Detecting Subtle Defects

Some defects that exist in print inspection are of such low contrast that they barely register much of a contrast difference from their surrounding once they are imaged. These very faint defects—such as squeegee marks, print scratches, and some surface textures (e.g., “orange peel” surfaces)—require special algorithms to extract them from a complex printed image. The best print inspection systems will use:

+ Multiple images of the same scene imaged under identical lighting conditions to create an averaged result. This will create a better Signal to Noise (S/N) ratio between the feature and the electrical noise in the video signal by averaging out the electrical noise, which tends to be random. A better S/N ratio will improve the ability of the print inspection system to extract small contrast defects (sometimes with as little as 2-5 grey levels above the noise floor) from a printed background.

+ Multiple images of the same scene, each with different lighting conditions (e.g., different light sources or different intensities of the same light sources) to create a different effect on the printed pattern. This can create redundancies in the inspection process that can improve the robustness of the ability to detect subtle defects.

In such cases, the print inspection system must be designed with the ability to control the camera's exposure time and frame rate, and to turn on or off the different light sources quickly enough so that multiple images of the printed object can be acquired with different light sources or different light intensities. Depending on the requirements of the print inspection process, it may also be necessary to generate unique light intensity levels to suit each type of printed object.

Challenge #6
Properly Handling Edges to Not Create False Defects

The ability to detect low-contrast defects in a printed pattern demands the implementation of special algorithms to detect subtle changes in color. However, in implementing such sensitive algorithms, special provision must be made to handle edges properly.

Edge details on a printed image are subject to much more variability than the area of a printed label away from the edge. When zoomed in, an edge appears not like a straight line, but as a very rough line with a variable edge of the extent of ink. As a result, traditional print inspection algorithms detect printing defects much more frequently in the area of edges than anywhere else in an image. The problem is that the human eye also does not detect these defects as well because it can only see a smooth edge in the area of a color transition, masking some of the edge information present.

As a result, print inspection algorithms must relax the inspection criteria in the area of an edge so that some variation can be tolerated by the print inspection system. In such a way, a small pinhole would be ignored on an edge (because it is not easily detected by a human operator), but would be detected in a printed area away from the edge.

For optimum performance, the better print inspection processes require an advanced masking algorithm that will learn where the edges are in an image and create zones of relaxed inspection criteria to be able to match the defect detection capability of a human (along the edges of a print) without compromising the defect detection capability elsewhere in the printed image.

Edge changes are a classic example of the variants that naturally occur during the printing process. The automatic characterization of such variation is best handled during the teaching phase when a number of candidate images are presented to the camera and a composite “golden” master is synthetically generated. As the printed images vary, small changes to the printed image and edge artifacts get averaged out, so that they become less significant in the final master image, thus tolerating individual changes to edges.

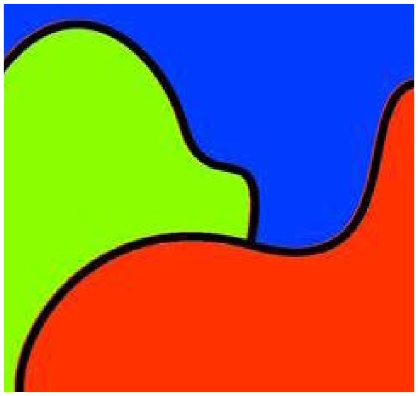
Challenge #7

Detecting "Blobs" of Subtle Color Change

Most subtle defects on a printed image will be small in area, but have a sharp color contrast to their surrounding areas. Examples of this include a scratch or pinhole on a colored zone that allows the substrate or base color to shine through. However, some very subtle defects that need to be found are similar to "watermarking" or staining on a printed page. These "blobs" are low-contrast defects that are characterized by a subtle change in color relative to their background across a large area of interest.

These types of defects are not as common as other more obvious defects, but are a common complaint of consumers of high-quality printed matter.

The ideal print inspection system should incorporate algorithms that are able to detect large blobs of a color change, where all the pixels in the blob are different in color by a few grey levels compared to their background. Such algorithms, when implemented correctly, are able to increase the print defect detection rate, without increasing the false reject rate of the system.



Color content at edges

Courtesy – www.artistaperegrino.com

Challenge #8
Avoiding Misalignment of Printed Images Under Inspection

Even the best print inspection systems have some mechanical variation from print to print. This mechanical variation is a result of the variation of the printing heads themselves and the ability to repeatedly locate the substrate in the same position between the point of printing and the point of inspection. For an on-line print inspection system, the smallest defect that can be detected is a sum of the mechanical variation of the printing machine and the systems variation of the print inspection process.

To improve this performance, the best inspection systems implement some types of alignment algorithms that can tolerate a slightly misaligned printed image prior to inspection. Such algorithms find key features in the image and perform a minor translation (in X or Y) or rotation to get the printed image lined up as closely as possible prior to inspection. The result of this form of pre-alignment is the print inspection's ability to find smaller defects in the printed image.

Printed Image Misalignment

Courtesy – www.stampauctionnetwork.com

Conclusion

A well-designed print inspection system is a complicated device to build. It is a combination of good hardware design in electronics, optics, and lighting, as well as good software design in process control and image processing. While difficult to achieve, careful design strategies and experience can produce a robust design to meet the exacting demands of the modern printing process.

Would you like more information?

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