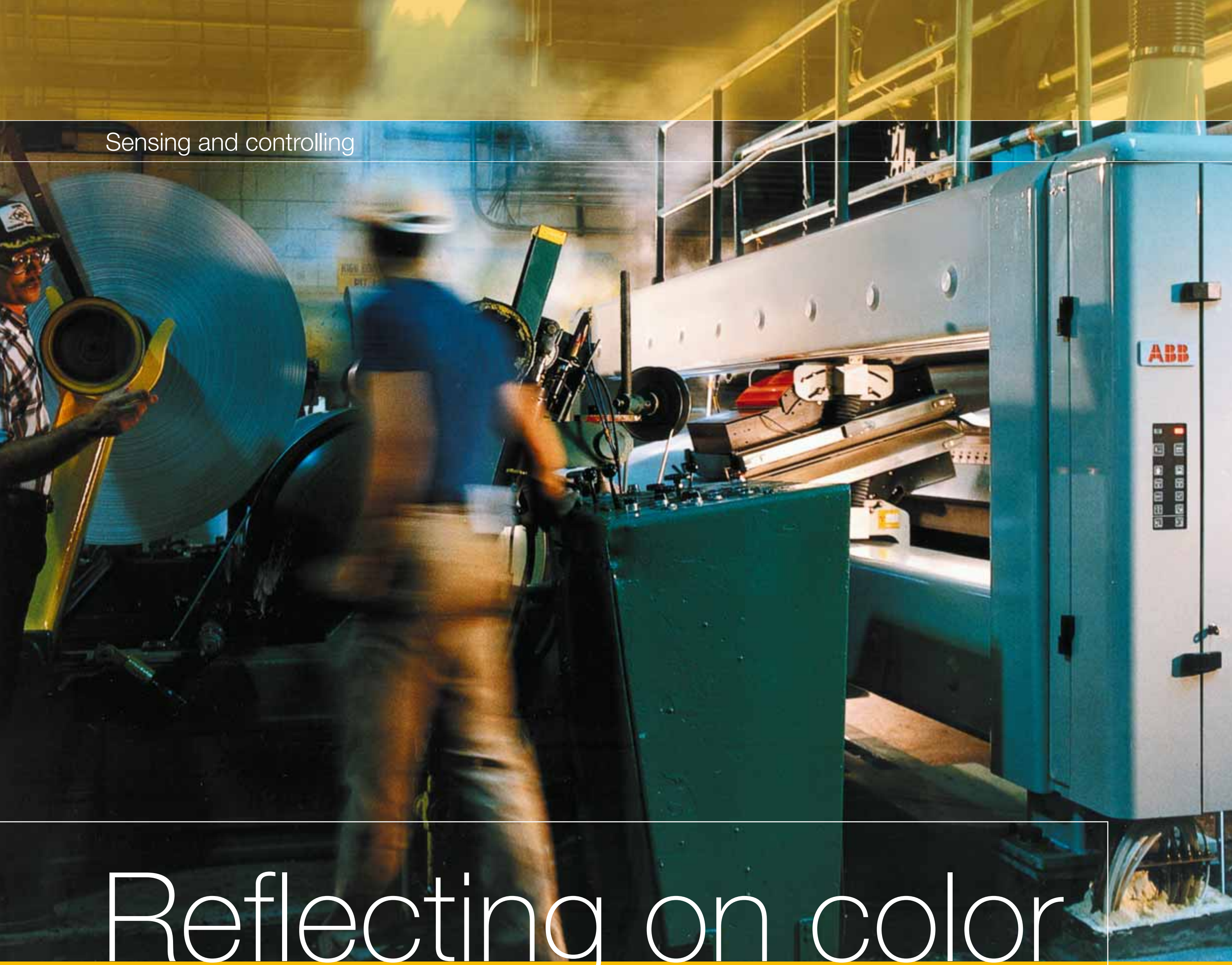

Reflecting on color

Color control technology for papermakers

Anthony Byatt, Steve Sturm

For a papermaker, getting the color of paper right is an important element of quality assurance. Customers expect envelopes to match their writing paper, and expect the paper they buy today to match the envelopes they bought months or even years ago. Different grades of paper manufactured with different machine settings can be required to have identical colors. Look carefully at this issue of ABB Review for example; the cover is slightly thicker than the other pages, yet the color matches precisely.

Reproducing color is no simple task and would not be possible if it were not for advanced color-control algorithms and highly sensitive instruments. But it is not just sensitivity and reproducibility that these instruments must tolerate, they must perform under harsh conditions such as high moisture levels and thermal and mechanical shocks.

In papermaking, even an unwritten sheet has a tale to tell. In this and the following articles, the amazing story of color control in paper is unfolded.

Television sales outlets normally have a broad selection of different types of TV sets on display. The electronics inside a color TV represents the pinnacle of high-performance, low-cost technology usage in a consumer appliance. An observer looking at one such screen cannot fail to be amazed by the brilliance of the colors displayed. But taking one step back and looking at the whole row of TVs on display, a subtle, and sometimes not so subtle, difference in color between identical TVs becomes clear.

To add to the complication, color is not absolute – perception of color is influenced by an individual's biology (some are color-afflicted or color-blind) as well as other effects. Perceived color, then, is a product of a light source output, an object's reflectance, and an observer's optical sensitivity.

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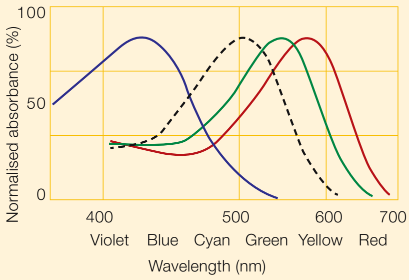
If achieving color consistency in this high-technology TV, built specifically for the purpose of true color reproduction is so difficult, then achieving it in a very humble, and apparently low-technology, product such as paper is very challenging indeed.

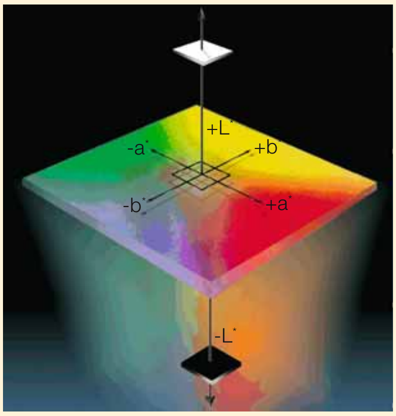
In paper manufacture, control of color – often actually whiteness – is critical. The continuous shift in the color of the dye in paper produced over a period of hours may be imperceptible to the human observer, but the difference in color can become very obvious when two sheets, one from the start and one from the end of the production run, are placed side-by-side. It would be unfortunate if these were to wind up as adjacent pages in a book. Paper appearance properties such as color, brightness, whiteness, opacity, and gloss have increasingly become the differentiating quality parameters in paper products.

1 Color perception

a Spectral absorbtion in the three types of cone cells of the human retina, and rod cells (dashed line)



b Representation of the L^* a^* b^* color space. Along the L^* axis, lightness varies from black to white



The retina of the human eye has three types of color-sensitive cells (known as cone cells). Each of these cell types is sensitive to a different range of wavelengths. These ranges peak at approximately 440, 544 and 580 nm (for blue, green and red light respectively). There is a considerable overlap a between the ranges, rendering the retina responsive to all frequencies between 400 and 700 nm.

An individual cone cell only reacts to the intensity of the stimulation. It can neither resolve the exact wavelength of the stimulating light, nor can it differentiate between monochromatic light (of a single wavelength) and polychromatic light (with a combination of different wavelengths). This represents a significant difference between color vision and hearing. In the latter case, humans can differentiate between wavelengths with considerable accuracy and the trained ear can even resolve the individual notes of a musical chord.

Despite this, humans can distinguish a broad range of colors. This is due to the cortex (the area of the brain concerned with vision) combining the signals from the three types of cone cells and interpreting every combination as a different hue.

In contrast to this perceived color system, the L^*, a^*, b^* color-space represents the real color of an object. L^* maps the lightness and a^* and b^* the magenta-green and yellow-blue variability respectively b.

(Figure 1a is taken from the Wikipedia encyclopedia and is subject to the GNU Free Documentation Licence.)

Manufacturers, then, go to great lengths to control the color of their product – and ABB provides them with the technology to do so, with advanced on-line color sensors and software to control the addition of colorants to the process.

Quantifying color appearance

Color is perceived via red, green and blue eye stimuli (tristimulus) 1. The description of color is not intuitive and is therefore subject to a rigorous scientific CIE[1] standard: L^*, a^*, b^*. There are many ways to quantify color appearance, but L^*, a^*, b^* is one of the more universal schemes.

The three parameters in the model represent the lightness of the color (L^*, $L^*=0$ yields black and $L^*=100$ indicates white), its position between magenta and green (a^*, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (b^*, negative values indicate blue and positive values indicate yellow).

When light hits a surface, it can be reflected, absorbed or scattered. Smooth surfaces reflect and rough surfaces cause diffuse scattering. A surface that

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Footnotes

[1] CIE (International Commission on Illumination – the abbreviation actually stands for its French name, Commission Internationale de l'Eclairage) is a Vienna-based scientific organization that is broadly accepted as an international authority on light, illumination, color, and color spaces.

diffusely reflects all wavelengths equally is perceived as white, while a surface that absorbs all wavelengths equally is perceived as black. Besides this diffuse reflection, specular reflection can also occur (as in a mirror). A good mirror reflects all wavelengths equally, but is not perceived as white because of its smoothness. Similarly, a black object can reflect light if it has a smooth finish.

2 The scanning platform

> ABB metrology experts have succeeded in finding ways to deploy the measurement principles in environments too harsh for constant human habitation.

This, then, is the arena for the on-line color control produced by the ABB Quality Control Center of Excellence, part of the Paper business unit, based in Dundalk, Ireland. This unit specializes in the on-line measurement of paper properties and implementing complex control schemes to optimize these properties automatically. Color measurement is a popular on-line control, utilized on 40 pecent of all quality control systems sold.

Modern instrument design

The color instruments used in quality control laboratories have become extremely sophisticated over the past 15 years. Nearly all high-quality instruments measure reflectance spectra of samples presented to the sensor. This generally requires a stable source of visible radiation and a complex optical system to gather reflected energy. Laboratory color instruments are operated by technicians: They test the calibration, select the type of color coordinates required, align samples and collect colorimetric data. These technicians perform this task every hour or so in a benign laboratory environment with few vibrations or shocks to the instrument, or, indeed, the technicians.

ABB's clients expect similar precision, reliability and ease of use from ABB's on-line instruments 2. These must operate without a technician for 24 hours a day, 365 days a year at temperatures of 60 °C and 100 percent humidity! Sometimes the instrument package vanishes into a cloud of water vapor as it traverses the sheet. Every few hours, the instrument spends some minutes off-sheet, in a suddenly 15 °C cooler environment, for test and calibration. In addition, shock of up to 4 gravities along any axis is common and vibration equivalent to 2 gravities between 5 to 500 Hz must be tolerated.

From the "any axis" shock point of view this is similar to dropping the laboratory technician onto a tiled floor from a height of about 390 mm onto his head – and still expecting quality measurements!

Where ABB excels, color measurement

Rising to these challenges, ABB metrology experts have succeeded in finding ways to deploy the measurement principles in environments too harsh for constant human habitation. The instruments must not only survive, they must operate continuously and provide data that rival laboratory instruments in accuracy and precision.

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The Land effect

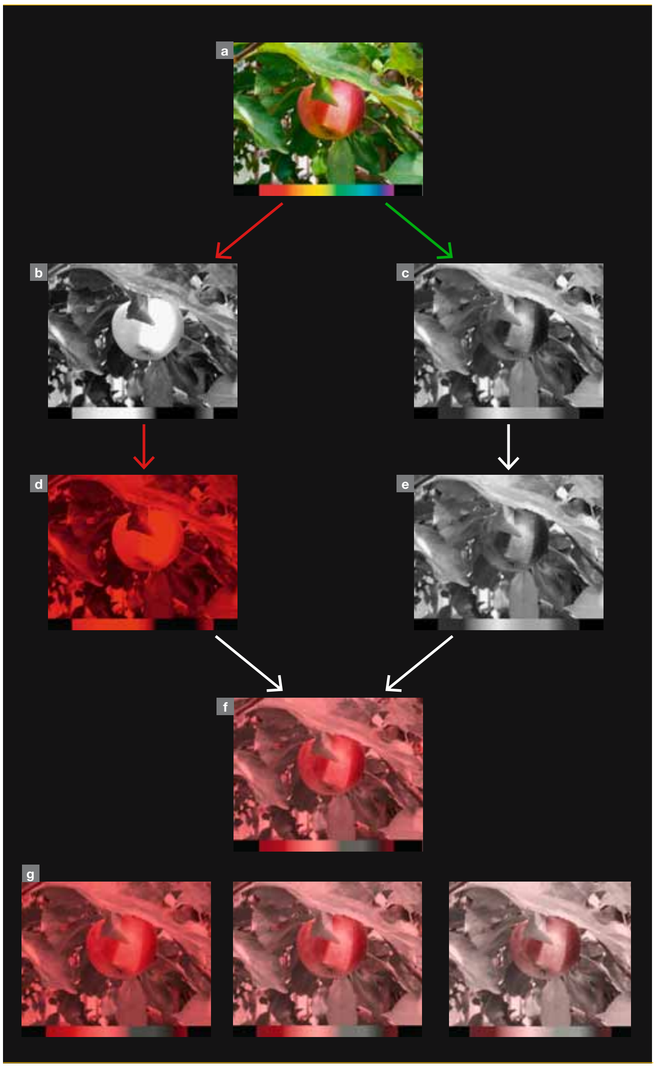
The deviousness of color is amply demonstrated by the so-called Land Effect. This effect was described in 1977 by Edwin Land (better known as inventor of the Polaroid camera).

Humans interpret objects as having constant color, regardless of the illuminant (daylight, artificial light, etc). For example, grass that appears green in intense sunlight retains its green color under a street light at night, despite the different intensity and spectral composition of these light sources. Land postulated that we perceive an object's color by comparing the trim-stimulus input from its reflectance (see also figure one on page 41) with that of adjoining objects.

In photograph 1, several colors are visible. Or are they? In fact, this is a monochrome red picture with a black and white overlay. The only "real" color present is red. However the brain introduces other colors, including various shades of green and brown. (The picture is best viewed in artificial light which is slightly yellow.)

1 What colors does this picture contain?

2 The steps that went into the creation of 1



Land demonstrated[1] this effect by taking two photographs of the same scene 2a using black and white transparency film – one photograph was taken through a red filter 2b, and one through a green filter 2c. He then used two projectors to superimpose these pictures. He placed a red filter in front of the projector with the corresponding picture 2d, but left the picture that had been made with a green filter in black and white 2e. The resulting projection is shown in 2f. Whereas neither of the composing pictures has any green, this color appears to be contained in the resulting scene. The appearance of the colors can be fine-tuned by changing the relative intensities of the projectors 2g. The perception of these scenes varies with the light under which they are viewed.

The Land Effect is an interesting illustration of how easily the brain is "fooled" into seeing colors, underlining the value of an absolute system of color measurement.

Footnote

[1] Today, it is far simpler to recreate this experiment using the channel mixing functions of software such as Adobe Photoshop (as indeed was done here).