A High-speed and High-precision Color Sensor for Improving Color Management in the Paper-making Process

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Thanks to the expanding retail business, the paperboard market in Asia is growing and thus the demand for paper color control is increasing. To meet this need, online measurement of paper chromaticity in the paper-making process is used to ensure strict quality control of paper color. Yokogawa has enhanced the functions of the LED color sensor for the B/M9000VP paper quality control system. A new high-sensitivity spectroscope enables high-sensitivity and high-speed measurements, and a moisture-proof coating on components has improved moisture resistance. With the enhanced functionality and robustness of the LED color sensor, the B/M9000VP has improved quality control in the paper-making process.

INTRODUCTION

The paperboard market is expected to continue growing in China and other Asian countries, and thus the demand for paper color control is increasing. For example, although paperboard is increasingly used in the food industry as recyclable, sustainable packaging material, it needs to satisfy a high level of color quality because its appearance has a significant impact on sales.

The LED color sensor mounted on Yokogawa's B/M9000VP paper quality control system provides on-line measurement of quality characteristics related to paper color during the paper-making process. Moving across the surface of the paper web, the LED color sensor obtains color information at multiple measurement points, sends the data to the system, and outputs a chromaticity trend. From the results, the B/M9000VP evaluates the uniformity of the color. If necessary, the system also provides feedback to the coloring control unit to ensure consistent color quality.

Since dissolved pulp is dried at high temperatures, the paper-making process is subject to a hot and humid environment, which affects some optical components used in color sensors. To overcome resulting indication changes and other problems, humidity countermeasures are taken such as purging the inside of LED color sensors with dry air or by heating them up. However, since utilities are turned off during maintenance and inspection, it is necessary to improve the moisture resistance of optical components.

To address these issues and improve color management in the paper-making process, we have developed a new LED color sensor with high sensitivity and high speed. We use a high-sensitivity spectrometer that can perform high-sensitivity, high-speed measurement and output color profiles. Moisture resistance has been improved with a special moisture-proof coating on the components, enhancing the functionality and stability required for color measurement in the paper-making process. Table 1 shows the main specifications of the color sensor head, and Figure 1 shows its external view.

Table 1 Main specifications

Irradiation/detection condition	45° a: 0° (annular irradiation)
Measurable and displayable range	Wavelength: 400-780 nm Reflectance: 0-130%
Measurement items	Values of each dimension of CIE L*a*b*, Hunter Lab, CIE Yxy and CIE XYZ color space, ISO brightness, CIE brightness, fluorescence whitening effect
Light source	High-brightness white-LED UV-LED (for measuring fluorescence whitening effect)
Spectral measurement cycle	6.3 ms

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Figure 1 External view of the new LED color sensor

OPERATION OF THE COLOR SENSOR DURING THE PAPER-MAKING PROCESS

The new on-line LED color sensor offers excellent reliability and stability. It uses white- and UV-LEDs as light sources and irradiates light through the optical system onto the paper web. The spectrometer receives the light reflected from the surface of the paper, and the calculation unit calculates the reflection intensity at each wavelength. The measured reflection intensity is normalized and calibrated with the predetermined values in the white tile calibration. The LED color sensor then outputs the reflectance spectrum of the paper. With this output and the predetermined light source settings, the LED color sensor calculates the industry-standard color system, CIE whiteness, ISO brightness, etc. and outputs the results.

Fluorescent brighteners are used in paper manufacturing to increase apparent whiteness. The new LED color sensor can determine their effect by measuring the whiteness of the paper web when a high-brightness UV-LED is turned on and off.

There are many sources of illumination and disturbance around the paper-making line. To compensate for the influence of these disturbances, the LED color sensor runs in three modes, 6.3 ms for each: both LEDs on, white-LED only on, and both LEDs off. Since the values measured during the both-LEDs-off mode are from ambient lighting, these values are subtracted from the data in the other modes.

The new LED color sensor is also equipped with functions necessary for on-line color measurement, such as path line correction[1] to compensate for the variation in the distance from the measurement window to the surface of the paper web flowing through.

According to the measurement principle, the new LED color sensor alternately irradiates light while repeating the above three modes. If the paper is uneven and the measurement cannot be performed at high speed, it is difficult to achieve simultaneous measurements at the same point, reducing the reliability of the measured values. For this reason, we increased the sensitivity of the measurement, accelerated the calculation, and stabilized the values of measurements.

TECHNOLOGY FOR ENHANCING FUNCTIONALITY AND STABILITY

High-sensitivity Back-illuminated CCD Spectrometer

High-sensitivity measurement in the UV region

The two independently controllable LEDs, white and UV, are used as light sources. The sensor can make LEDs flash at high speed. The influence of ambient light can be eliminated by subtracting the measurements when both LEDs are off from those when at least one LED is on. Figure 2 shows the spectral characteristics of the UV- and white-LED; the combination of the two LEDs ensures high sensitivity in the UV region.

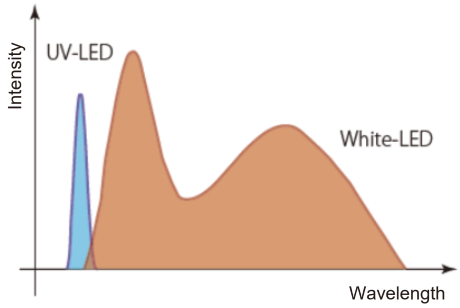

Figure 2 Spectral characteristics of the UV- and white-LED

By controlling the UV- and white-LED independently, the sensor can perform measurements with and without fluorescence effect. The three irradiation modes (6.3 ms for each) are repeated with a cycle of about 19 ms (Figure 3), during which the data is collected and averaged. Information such as chromatic value, brightness, fluorescence intensity, opacity, and whiteness can be calculated from the spectral measurement results.

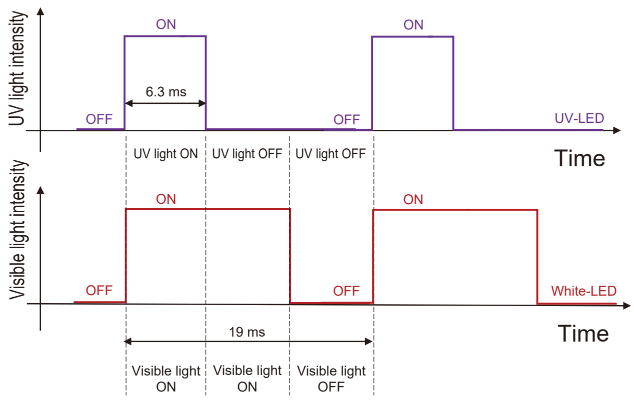

Figure 3 Controlling the turning on and off of the LEDs

The new LED color sensor uses a spectrometer equipped with a high-sensitivity back-illuminated CCD detector, enabling even more stable measurements. This has resulted in the following improvements.

■ Etaloning characteristics:

Light waves of incident light interfere with each other at the surface and back of the detector, affecting the sensitivity. This phenomenon is called etaloning. The reflection intensity spectrum is affected as shown by the dashed line in Figure 4. The back-illuminated CCD detector used in this product has greatly reduced this effect, making its optical sensitivity characteristics nearly flat over the wavelength range.

- Linearity characteristics:
  Linearity characteristics have been improved in the range used for measurement, which eliminates the need for the conventional linearity correction function in LED color sensors.
- Higher sensitivity in the region of UV to near-infrared:
  The new spectrometer has increased the spectral analysis sensitivity in the range of UV to near-infrared (approximately 40% improvement over conventional spectrometers) and improved the stability of measured values.

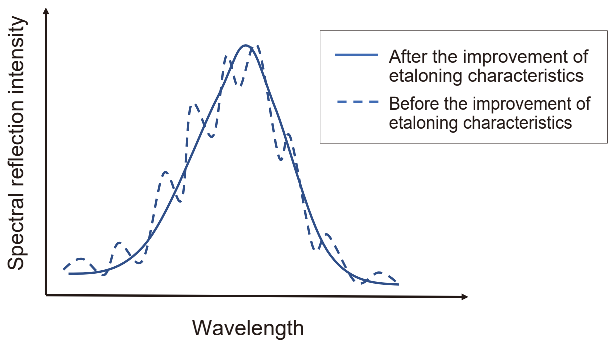

Figure 4 Etaloning characteristics reduced by the back-illuminated CCD

High-speed measurement

For stable measurements, we set the wavelength resolution of the color sensor to 5 nm, which is higher than that required for conventional LED color sensors. The sensor also needs to be able to process data to determine the presence of fluorescent components, correct the data for disturbances such as stray light, and so on. The sensor must also satisfy the requirement of the 200-ms measurement output cycle, one-fifth of the conventional cycle. To achieve high-speed processing of a large volume of data, we mounted the primary processing computational engine on the spectrometer, and the application engine on the main unit of the color sensor; the former collects spectral data and performs primary processing and the latter performs subsequent processing. The primary processing computational engine is able to obtain the 6.3-ms exposure data and calculate the average during the measurement cycle of 200 ms. Specifically, this engine is responsible for controlling the turning on and off of the UV- and white-LED, obtaining exposure data, measuring workpiece distance and correcting brightness, averaging the corrected spectral data over time, and outputting the data to the application engine.

As described above, the primary processing computational engine needed to be able to perform not only general processing required for general-purpose spectrometers such as averaging but also application-specific processing required for color sensors. We worked with a Japanese spectrometer manufacturer with a proven track record in spectral analysis and developed a high-performance engine. Figure 5 shows the calculation flow covered by the primary processing computational engine and the application engine. With high-speed processing capability, the primary processing computational engine performs the path line correction before averaging, while the application engine performs other corrections for ambient light and UV light.

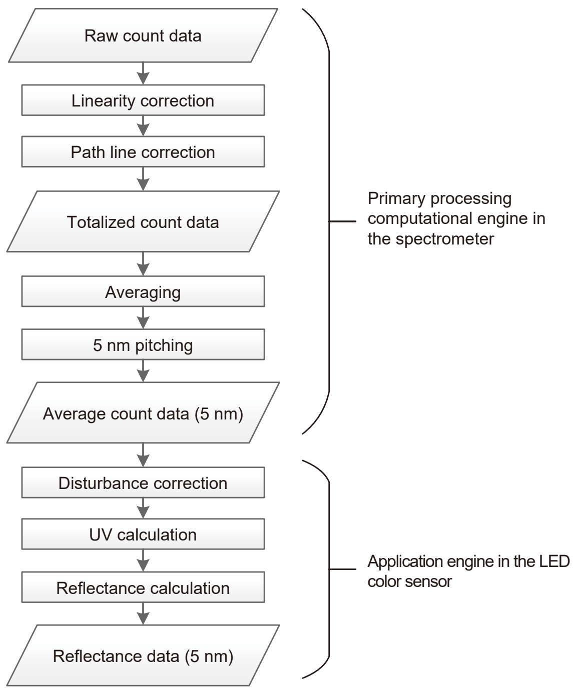

Figure 5 Calculation flow covered by the primary processing computational engine and the application engine

Switching the LEDs and averaging the data

To measure whiteness and fluorescence whitening effects, the new LED color sensor uses UV- and white-LEDs, both of which can be independently controlled.

One cycle of illumination (19 ms) consists of 3 slots (6.3 ms each). The UV-LED is turned on in one slot and the white-LED in two slots. With this scheme, the spectral data can be totalized with and without fluorescence whitening effects separately, and their averages can be output to the application engine. In addition, the output data are compressed, which eliminates the need to use a high-speed interface and shortens switching intervals, achieving simultaneous measurement on the same spot.

Even if the reflectance of paper is constant, the amount of light reflected from the paper varies in proportion to the measurement distance. In addition, it is difficult to maintain the distance from the light source to the workpiece constant in on-line measurement. Therefore, the new sensor measures this distance and corrects the spectral light intensity accordingly.

Outputting the color profile

The high-speed primary processing computational engine in the spectrometer ensures that the sensor can stably output signals obtained through high-sensitivity, high-speed measurements and synchronize communication with the profile-display host system. Changes in color brightness, fluorescence intensity, opacity, and whiteness can be more easily understood. The additional measurement information can improve color management in the paper-making process such as close monitoring of coating profiles. This feature will enable us to add a color profile function to the B/M9000VP system.

Special Moisture-proof Coating for Improving Environmental Resistance

As mentioned earlier, the environment of the paper-making process is hot and humid, which can affect the physical properties of optical components and readings.

The new LED color sensor uses an integrating sphere to mix two LED lights homogeneously. The integrating sphere is generally made by solidifying barium sulfate powder with polyvinyl alcohol (PVA). Since PVA is hygroscopic, the reflection and scattering efficiencies on the surface of the integrating sphere vary greatly depending on the ambient humidity. Figure 6 shows the effect of a moisture-proof coating on the reflectance spectrum. With a conventional integrating sphere without a moisture-proof coating, reflectance changes in the short wavelength range of 400 to 500 nm, and it takes time for readings to stabilize.

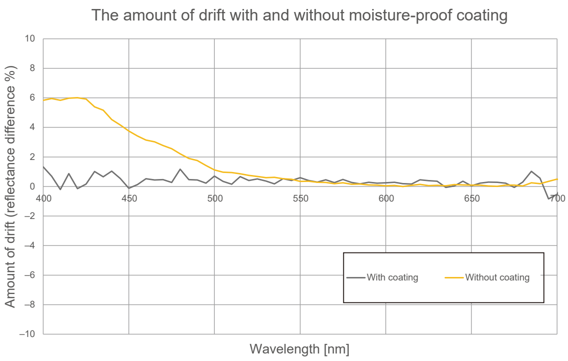

Figure 6 Changes in reflectance spectrum caused by humidity (Comparison between with and without moisture-proof coating)

In the new LED color sensor, the surface of the integrating sphere is coated with a special moisture-proof material with high water repellency. This prevents reflectance changes caused by humidity. As shown in Figure 6, the reflectance change was suppressed to less than 1% even in the short wavelength range.

This coating agent also has a dustproof effect, which has been confirmed to withstand outdoor use. The efficiency of the integrating sphere is expected to remain stable over a long period of time. This will ensure stable measurements even in the humid environment of the paper-making process.

CONCLUSION

High-sensitivity, high-speed measurements have been achieved by using a high-sensitivity spectrometer, and moisture resistance has been improved by the special coating on the components. Through these innovations, the functionality, stability, and maintainability of the LED color sensor have been enhanced, improving color management in the paper-making process.

The new LED color sensor can stably output the reflectance data, which can also be used for color coating control in the paper-making process. We will continue to develop a coordinated optimization solution that uses manufacturing trend data in the paper-making process to improve the operational efficiency of the entire process.

REFERENCES

(1) Atsushi Tsujii, Minoru Terajima, et al., “A High-precision Color Sensor for the B/M9000VP System,” Yokogawa Technical Report English Edition, Vol. 56, No. 1, 2013, pp. 35-38