A High-precision Color Sensor for the B/M9000VP System

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Yokogawa has developed a new LED color sensor for the B/M9000VP paper quality control system. A high brightness LED as a light source ensures accurate and stable measurement, and a high power UV LED enables continuous measurement of the fluorescence whitening effect. In addition the long life light sources reduce maintenance work. The optical system with greater depth of focus and the newly developed wavelength shifting method (WSM) for ranging correction eliminates the influence from paper fluttering and wrinkles. This paper describes the features of this color sensor.

INTRODUCTION

In the paperboard market, which is expected to grow in China and other Asian countries, demand for paper color control has recently been increasing. To satisfy this demand, Yokogawa has developed a new color sensor for the B/M9000VP system, a measurement and control system for both paper and coating machines. The B/M9000VP is an online paper quality measuring and controlling system with various sensors mounted on a dedicated frame head, including such sensors as for basis weight, moisture, paper thickness and ash content. The frame head moves over the surface of the paper in the process. The new color sensor is one of the sensors mounted on the frame head.

Figure 1 shows an external view of the new color sensor, and Table 1 lists the main specifications.

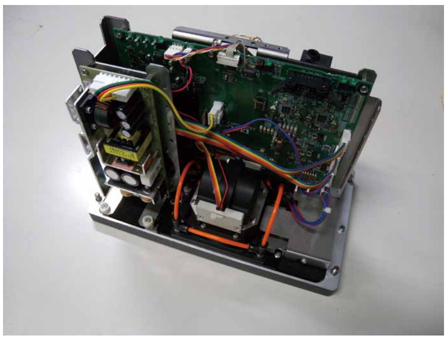

Figure 1 An external view of the new color sensor

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Table 1 Major specifications of the new color sensor

Irradiation/detection condition	45° a: 0° (Annular Irradiation: perpendicular detection)
Measurable and displayable range	Wavelength: 400 to 780 nm Reflectivity: 0 to 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 CIE: Commission internationale de l'eclairage.
Light source	High brightness LED UV LED (for measuring fluorescence whitening effect)

ISSUES FOR A COLOR SENSOR USED FOR A B/M SYSTEM

A color sensor for a measurement and control system for paper machines and coating machines (hereafter, such a system is referred to as the “B/M system,” where B/M stands for basis weight and moisture) uses a measurement principle similar to that of a usual spectrocolorimeter. However, there exist some issues specific to online sensors used for paper making process.

The head unit of a B/M system keeps moving over the surface of paper during processing. Therefore, sensors on the head unit are exposed to vibrations caused by this mechanical motion, which result in a harsh condition for a color sensor composed of precision optical components. Even if there is a problem only with the color sensor, a measurement cannot be interrupted for inspection, as not only a color sensor but also other sensors such as basis weight, moisture, paper thickness and ash sensors are mounted on the head.

Thus failures and replacements of any components of the color sensor used for a B/M system should be eliminated as much as possible. It is also desirable that the sensor status be able to be checked without interrupting the measurement.

Spectrocolorimeters usually measure color while keeping the sensor in contact with a sample. In other words, they are used keeping the relative position between the sensor and a sample fixed. Meanwhile, in the paper making process, paper is moving at the velocity of a few hundred to 2000 m/min, so it is hard to keep the sensor of a B/M system in contact with a sample during color measurement. Moreover, the fluctuation in paper basis weight and operating conditions cause unstable tension and fluttering, thus it must be assumed that the distance between the sensor and the sample paper is constantly changing.

To address these issues, existing color sensors for a B/M system apply a path line stabilization mechanism which utilizes oncoming air flow against the sensor to draw the paper near the sensor and suppress paper fluttering, which curbs change in distance between the sensor and paper. However, the path line stabilization mechanism cannot escape contact with the paper, causing problems such as paper breaks and paper powder generation, which affect the measurement.

In the development of the online color sensor for a B/M system, to respond to the issues described above, we have aimed for a reliable and stable measurement that is less susceptible to the influence of paper fluttering and wrinkles.

FEATURES OF THE NEW COLOR SENSOR

Features of the developed color sensor are as follows.

- A long-life high-brightness white LED (more than two times longer lasting than conventional ones)
- A high-power ultraviolet (UV) LED for measuring the brightness and fluorescence whitening effects to enable evaluation of the fluorescence whitening effect without any moving element
- Applying annular irradiation to eliminate the effect of fiber orientation and achieve excellent path-angle characteristics
- A compact integrating sphere and a cylindrical mirror to generate uniform irradiation light with a large depth-of-focus
- Applying the wavelength shifting method (WSM) to ensure stable measurement without a path line stabilization mechanism
- Uniform air blow from the fringe of the light transmission window to prevent paper powder accumulation on the window
- Constant transmission of information on temperature, voltage, etc. of parts of the sensor to the system to enable verification of the sensor status on a dedicated screen
- Integrating the irradiation and detection optics into one unit to eliminate the necessity of realignment of the optical axis and other tasks when assembling or replacing parts

The newly developed components featuring the color sensor are described below.

High-Brightness LED Light Source

A high-brightness white LED is used as the light source for the new color sensor, instead of conventional xenon lamps or halogen lamps. Thus, the life of the light source has become much longer, and the stability and reliability of the measurement has substantially improved because the high voltage for xenon lamps and the spectrum monitoring of a light source to correct instable light emission intensity are no longer necessary.

As a result, the related electric circuit has become remarkably simpler, which reduces the size and power consumption. Although the output characteristics of the LED vary with temperatures, the temperature of the light source part is locally controlled to be constant for stable emission without being affected by environmental changes.

Brightness Degree and Fluorescence Whitening Effect Measurements without Moving Parts

The light source must contain a certain amount of UV light to measure the brightness (ISO Brightness or CIE Brightness) of the paper. This is because the measurement reflecting the effect of fluorescence excited by UV is required when measuring paper which contains fluorescent brightening agents. When measuring the brightness, it is also required to measure the difference between the brightness evaluated with a light source that contains UV light and one that does not. This is the fluorescent whitening effect caused by the fluorescent brightening agents.

Conventionally, inclusion of UV light is controlled by inserting and removing a UV-blocking filter against the light including UV light. However, the existence of moving parts greatly deteriorates the reliability of a sensor used in a B/M system.

Thus, to measure the fluorescence whitening effect without UV-blocking filters, the new color sensor uses a high-power UV LED for fluorescence measurements combining the main white LED light source which does not contain UV light in the spectrum.

Switching the UV LED on and off in synchronization with the measurement frequency enables continuous and repeated measurement of the fluorescence whitening effect.

Figure 2 shows the comparison between the brightness (ISO Brightness) measurement results with the new color sensor and those with a laboratory-use brightness meter, when measuring ISO reference level 3 (IR3) fluorescent standard paper, paper samples (A through F) containing fluorescent brightening agents, and paper for plain paper copiers (PPC).

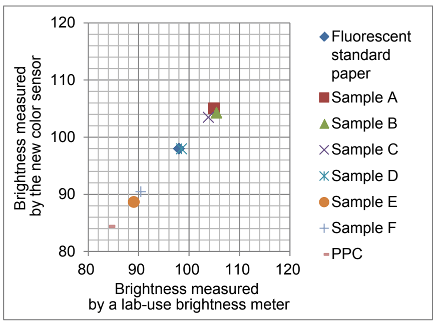


Figure 2 Comparison between the measurement results of the new color sensor and those of a laboratory-use brightness meter (ISO Brightness)

A strong correlation between the two sets of data was obtained.

Tolerance against Path Line Fluctuation

The issue of fluctuating distance between the sensor and the paper, described above, has been successfully resolved to achieve stable measurement by adopting new irradiation optics which are less sensitive to the path line fluctuation, and by developing a distance measurement real-time correction function for the effect of the fluctuation. Thus, the conventional method of suppressing paper fluttering is no longer required.

Optical system

Figure 3 shows a conceptual diagram of the irradiation and detection optics of the new color sensor.

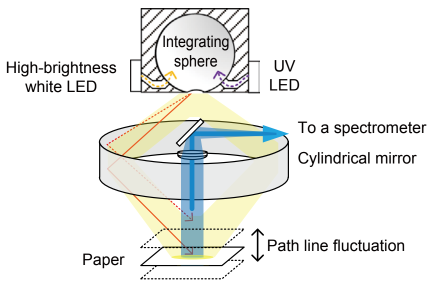


Figure 3 Conceptual diagram of the optical system

The light from two LEDs, a white LED and a UV LED, first goes into an integrating sphere and is homogenized. After exiting the integrating sphere, the light is reflected by the cylindrical mirror and irradiated onto paper from the entire surface of it. This keeps the balance between the visible light and the UV light constant regardless of paper position or tilt.

As shown in Figure 4, thanks to a cylindrical mirror, the variation of the illumination intensity at the measurement spot, that is the variation of the intensity of the light reflected by the paper, is less sensitive to the path line fluctuation.

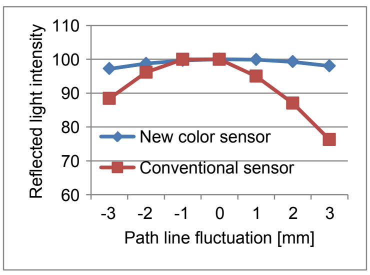


Figure 4 The effect of the path line fluctuation

Wavelength shifting method (WSM) for distance measurement correction

Even with the optics described above, the effect of the path line fluctuation on the measurement is not completely eliminated, as seen in Figure 4.

To resolve this issue, a wavelength shifting method (WSM) has been newly developed, in which the distance to the same spot as that of the color measurement is simultaneously measured and corrected. Figure 5 shows the structure for the WSM.

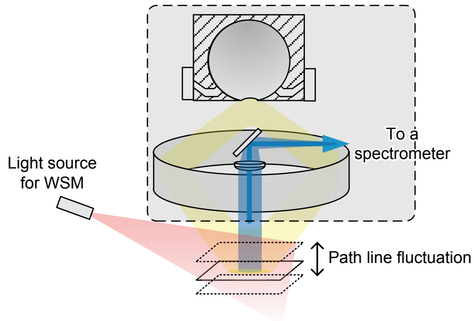


Figure 5 Structure for the WSM

The elements in the area surrounded by the dashed line in Figure 5 are the irradiation and detection optics of the color measurement; exactly the same as in Figure 3. The only additional element required for the WSM is a dedicated light source.

The procedure of the distance measurement correction by the WSM is described below.

1) Path line position detection by the WSM light source

The optics are uniquely designed so that the light from the WSM light source is characterized to have a spatial spectral distribution which varies with the path line position. The spectroscope detects this change in the spectral distribution, and the information which has a certain correlation with the path line position can be obtained (hereafter, this is referred to as the “WSM feature value”). As shown in Figure 6, the infrared region (around 800 to 900 nm) is used for the WSM light source so as not to affect color measurement.

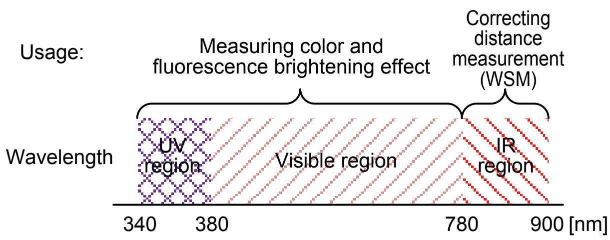


Figure 6 Application of each wavelength region in the optical spectrum

2) Determining the correction coefficients used for the WSM (correlation between the intensity and the WSM feature value)

Then, the relation between change in the reflected light intensity caused by the path line fluctuation and change in the WSM feature value is approximated by a polynomial, and the coefficients in the polynomial are determined as illustrated in Figure 7.

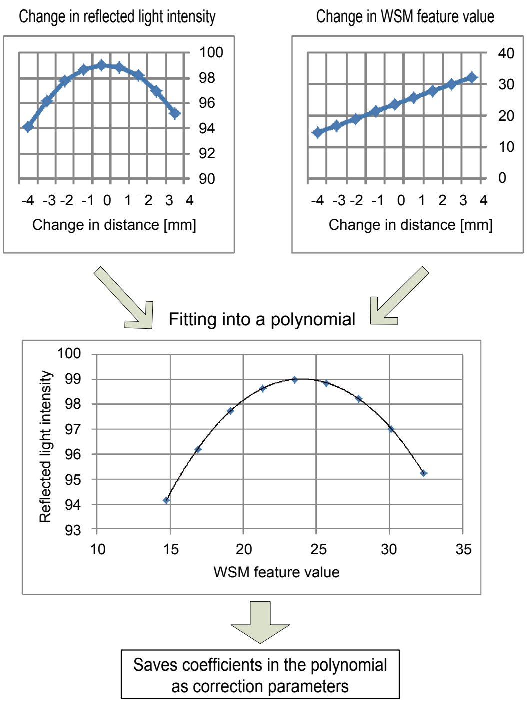


Figure 7 Determining correction coefficients used for the WSM

3) Distance measurement correction

During the actual measurement, the polynomial is calculated to obtain reflected light intensity by using the WSM feature value obtained from the infrared region of the optical spectrum and the coefficients determined in the step above, and then the reflected light intensity to be corrected is corrected for path line fluctuation by using the obtained reflected light intensity. Figure 8 shows an example of the correction by using the WSM.

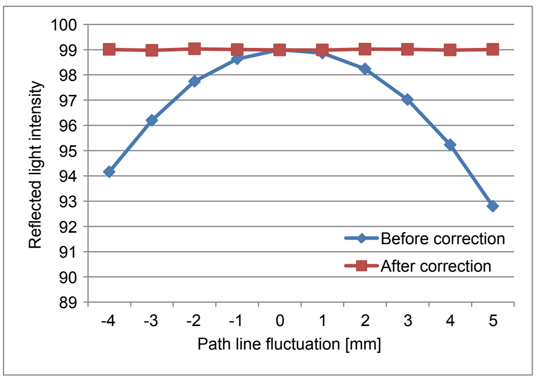


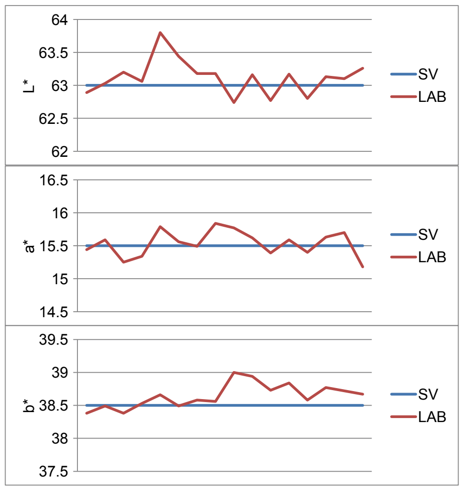
Figure 8 Comparison of the reflected light intensity before and after the correction

The merits of the WSM are summarized below.

- The only additional element required for the WSM is a dedicated light source.
- Information on the distance is obtained from the same spectrum as that used for the color measurement, which allows for a simultaneous and real-time correction being applied at the same spot as that of the color measurement.
- The distance and color are measured at the same spot. Therefore, the measurement is less susceptible to paper wrinkles or slanting.

FIELD EVALUATION USING PROTOTYPE

In the actual production process, a prototype of the new color sensor was used and the controllability of the B/M9000VP system using the measurement results was evaluated. The prototype was installed on a sensor flame and connected to the B/M9000VP system, and automatic color control based on the measurement results of the prototype was performed by the B/M9000VP system. Figure 9 shows the results of this evaluation. In the figure, SV is the target value for automatic control, and LAB is the value measured by an off-line color meter on the samples from each paper reel.



L*, a*, b* : Values of each dimension of CIE (L*, a*, b*) color space

Figure 9 Control target values and values measured by an off-line color meter (for 12 hours)

The off-line measurement values are all within the control limits and satisfactory measurement/controlling results were obtained.

CONCLUSION

Yokogawa has developed a new color sensor which is less susceptible to the fluctuation of the distance to the sample and can be applied to non-contact measurements. These features enable it to extend its application area to various online color measurements other than for the B/M system. Yokogawa will expand the applicable market by adding new functions to it and improving its functions, and will pursue further evolution of the color sensor for increased customers' benefits.