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Development of a Small Built-in Spectrophotometric Sensor for Color Printers

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Abstract

A key requirement on color printers is maintaining accurate color reproduction in output images. Reproducing the same colors more precisely on the same printer or between different printers requires a color calibration process involving precise measurement of the output sheet's chromaticity and subsequent chromaticity adjustments. This sort of color calibration has conventionally been a complicated offline process, involving placing and measuring the output sheet in a standalone colorimeter and then editing and adjusting print data based on the colorimetric data. Usability improvement and space saving in this process have been needed. And with the growth seen in the digital color press market in recent years, expectation for the inclusion of more accurate colorimetric sensors and more sophisticated automatic color matching are increasing. In response, we developed a spectrophotometric sensor with excellent colorimetric precision that is small enough to fit inside a color printer. In this paper, we report on the optical technology that was a key to reducing the size of spectrophotometric sensor and examples of applications using the digital press device, imagePRESS C10000VP, which makes use of the developed sensor.

Introduction

Along with maturity of the POD market in recent years, the demands for more accurate and stable color reproduction in image output from digital press devices have been increasing. Various manufacturers are trying to meet the demands by rolling out models with optical-density sensors placed after the fixing process for auto gradation adjustment. Such functionality has allowed manufacturers to provide satisfactory operating conditions that alleviate users from traditional labor intensive work of printing test patterns and measuring their colors offline.

Given such circumstances, we have been working to develop a small spectrophotometric sensor capable of surpassing single-color gradation adjustment and providing color tone correction, with the objective of achieving more advanced color matching from the viewpoint of color reproduction.

The small spectrophotometric sensor discussed in this paper was developed on the assumption that it would be located along the paper path of an electrophotographic printer. In order to fit the sensor along the printer's paper path, the sensor incorporates technology to minimize its physical dimensions, particularly its height, as well as optical design technology to perform highly accurate colorimetric measurements on output sheets being delivered in the printer. Using these technical approaches, we achieved the world's smallest spectrophotometric sensor with a built-in illumination light source. And locating the sensor along the printer's paper path facilitates inline color calibration, including precise colorimetric measurements of the output sheet.

The developed sensor has been included on Canon's imagePRESS C10000VP printer series, announced in September 2015. The printer offers an extra dimension of automatic calibration functionality, by supporting precise color tone correction, over conventional gradation adjustment.

Here, we will report on the optical technology that is a key in reducing the photometric sensor's footprint and also the practical application of the sensor.

Overview of the Small Spectrophotometric Sensor

Fig. 1 shows the basic configuration and components of the small spectrophotometric sensor, and Table 1 lists its main specifications.

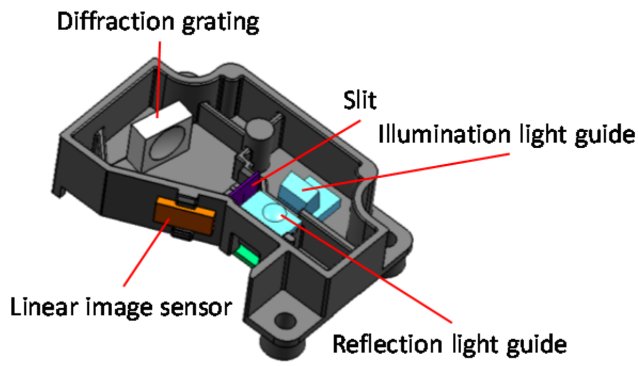

***Figure 1.** Diagram of sensor.*

The sensor adopts the Rowland type spectrometer structure, which has an advantage in making it small because of its simplicity. Inside the sensor chassis are an illumination light guide, a light guide for light reflected from the colorimetry target, a slit, and a concave reflective diffraction grating. The diffracted light is detected with a CMOS linear image sensor.

A circuit board with the microprocessor chip that performs the sensor's calculations and a white surface-mount LED that serves as the illumination light source is mounted underneath the chassis on the outside.

Table 1. Sensor specifications.

Instrument size	W53mm×D35mm×H18mm
Filter	Not available
Light-illuminating / Light-receiving	45° / 0°
Illumination method	Illuminating with one direction
Light receiving element	CMOS linear image sensor
Spectral method	Concave diffraction grating
Light source	White LED
Spectral range	400nm−700nm
Spectral resolution	10nm
Measured value	Spectral reflectance and CIE-L*a*b* value (D50/2°)
Reflectance range	0～110%

Fig. 2 provides a schematic diagram of the sensor's optical system. Light emitted from the LED passes through an aperture in the chassis's bottom surface and enters the illumination light guide. The light rays pass through the cover glass, via the light guide, and strike the colorimetry target located above the schematic.

Light reflected from the colorimetry target is collected with the reflection light guide. The light rays are bent 90 degrees and directed to the slit.

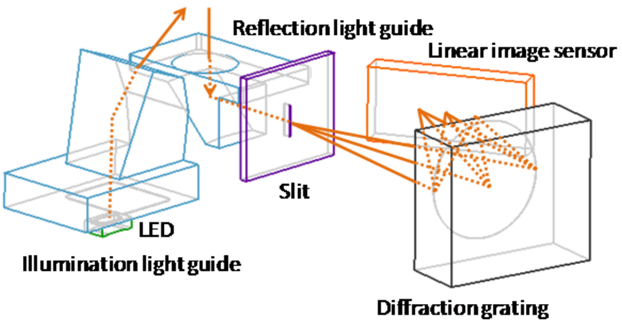

Figure 2. Diagram of sensor.

As Fig. 3 illustrates, a Rowland type spectrometer locates a slit and a diffraction grating on the Rowland circle. Diffracted rays of the same wavelength gather at the same position along the Rowland circle. By placing a linear image sensor as a photodetector at these positions, it is possible to detect the intensity distribution of the diffracted rays dispersed by wavelength.

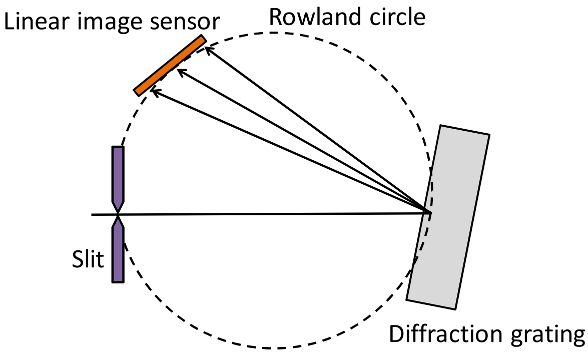

Figure 3. Rowland type spectrometer.

Optical Design

The optical system's design and technology were particularly important for making the sensor small and achieving high colorimetric measurement accuracy.

Designed for making the sensor small

The design of the receiving optics is the most important technology in reducing the size of the sensor, particularly in minimizing the sensor's height. Fig. 4 illustrates a schematic diagram of the sensor's reflection light guide. The reflection light guide has a convergence effect, in which the light rays reflected from the read region are made almost parallel by the incident surface of the convex spherical surface.

The light rays collected at the incident surface are entirely reflected by the reflection facet (A), which is placed at a 45-degree angle to the light rays, and thereby directed at the slit.

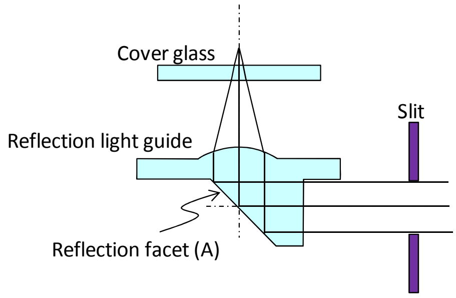

Figure 4. Reflection light guide.

In other words, the light rays reflected from the colorimetry target and collected at the incident surface are bent in a plane parallel to the colorimetry target plane by the reflection facet (A). The diffraction grating — which disperses the light rays after passing through the slit — and the line sensor — which receives the diffracted rays from the diffraction grating — are also positioned in a plane parallel to the colorimetry target plane, as shown in Fig. 2. This configuration enabled us to minimize the height of the sensor.

Fig. 5 illustrates the difference in sensor height when using two different configurations. In Configuration 1, the light rays collected at the reflection light guide's incident surface are bent, whereas in Configuration 2, they are not bent.

This demonstrates that the bending optical design can shrink the optical system height to 1/3rd.

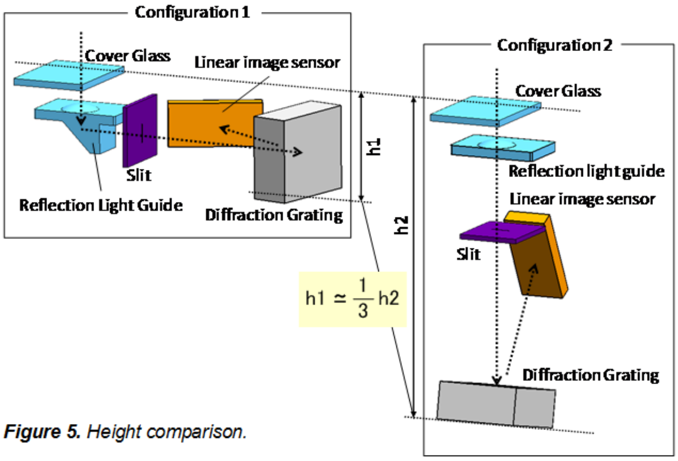

Figure 5. Height comparison.

Designed for paper-path colorimetric measurements

As stated in Introduction, the sensor was developed on the assumption that it would be located along the paper path of an electrophotographic printer and that the colorimetry target would be an output sheet being delivered in the printer. One of the first issues observed by taking colorimetric measurements of output sheets while being delivered is positional variations in the output sheet's vertical direction (i.e., perpendicular to the paper surface) caused by the delivery action.

The sensor design must minimize the impact of positional variations on the colorimetry results even in conditions where the distance between the sensor and the colorimetry target varies. This is an issue not seen on conventional offline colorimetric devices, which assume measurements are taken with the aperture pressed against a stationary colorimetry target or with the colorimetry target fixed by some means, such as electrostatic attraction.

Simulations were used to determine the optimal illumination optical system. We simulated the line sensor's light reception variation characteristics (i.e., the depth characteristics) caused by variations in the colorimetry target's vertical position when using a white lamp type LED as the illumination light source. Fig. 6 summarizes the simulation results.

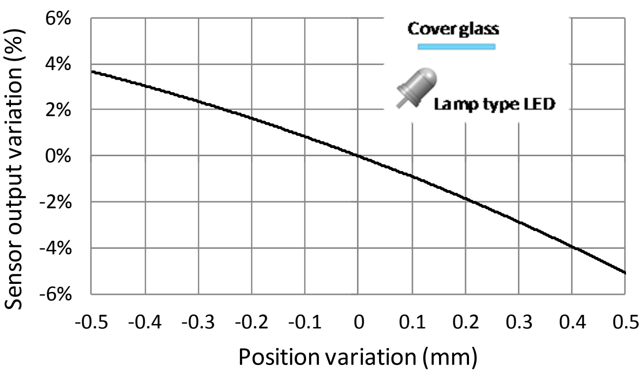

Figure 6. *Sensor output variation using lamp type LED.*

The simulations showed that when using a lamp type LED, positional variations produced significantly large sensor output variations that could not be ignored in a colorimetric sensor being designed for advanced color matching. From this result, we realized that the illumination optical system required improvements.

We next tried a white surface-mount LED as the sensor's illumination light source and adjusted the optical path design of the illumination light guide to see if we could achieve a flatter depth characteristic.

Fig. 7 shows a cross-sectional schematic diagram of the sensor's illumination light guide. Surface-mount LEDs have an angular light distribution characteristic, in which the maximum light intensity is produced at an angle of around 90 degrees to the emitting surface, with the light intensity steadily tapering off as the angle from the perpendicular increases.

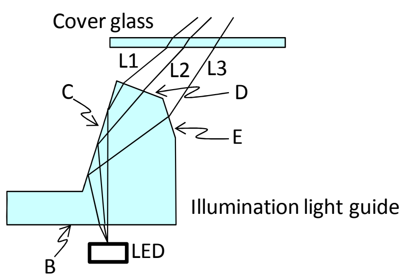

Figure 7. *Illumination light guide.*

Fig. 7 depicts the optical paths of three light rays — L1, L2, and L3 — emitted from the LED. The light rays emitted from the LED enter the illumination light guide's incident facet (B) directly above the LED, where each light ray is refracted. Next, the light rays enter and completely reflect off reflection facet (C). The totally reflected light rays are refracted again by refraction facet (D) or (E) before reaching the colorimetry target. By directing the emitted light rays to the colorimetry target with the effect of the reflection and refraction facets that are angled for the strongest light ray L1, we can reduce fluctuations in the light intensity that reaches the colorimetry position even when the distance to colorimetry target's surface is subjected to variations. Fig. 8 reproduces the simulation results of the depth characteristic when the sensor's illumination light guide is used.

This result indicates that variations in the received light intensity at the sensor, caused by variations in the colorimetry target's position perpendicular to the sensor, are greatly reduced when a surface-mount LED and illumination light guide are used in comparison to when a lamp type LED is used.

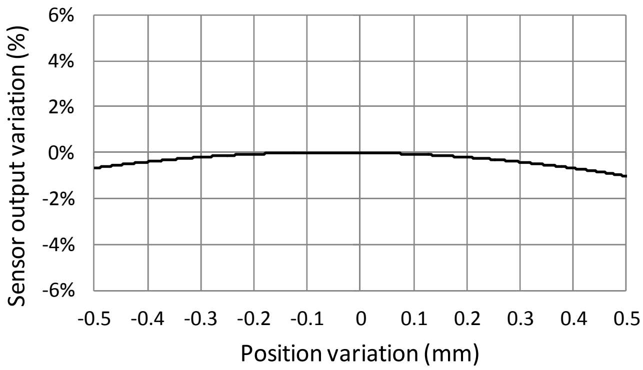

Figure 8. *Sensor output variation using surface mount LED and illumination light guide.*

In order to form and measure the color of many calibration patches on output sheets being delivered at high speed, light reflected from the patches must be collected very efficiently. The sensor is constructed so that light reflected from reflection facet (A) of the reflection light guide described above converges at the slit position (Fig. 9).

With this configuration, light passing through the slit has an intensity of about twice as that of a configuration in which reflection facet (A) does not converge the light rays.

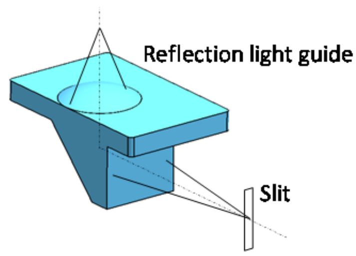

Figure 9. *Diagram of concentrated reflection light.*

ImagePRESS C10000VP

The imagePRESS C10000VP, which was announced in September 2015, is the flagship model of the imagePRESS production printer series. In addition to providing stable high-speed output of 100 images per minute (LTR), the fastest speed among the series' color models, it offers both high image quality and high reliability.

Additional functions and sensor mounting

The imagePRESS C10000VP series, in addition to auto gradation adjustment for each CMYK color, uses the sensor developed in this paper to automatically correct the color tone of compound colors (multicolor calibration). A single button automatically controls chart printing, color measurements, and correction, thereby automating the sequence of operations for gradation adjustment and color tone correction.

Figure 10. *imagePRESS C10000VP.*

The imagePRESS C10000VP series uses four sensors mounted in parallel at the switchback paper path after the fusing unit.

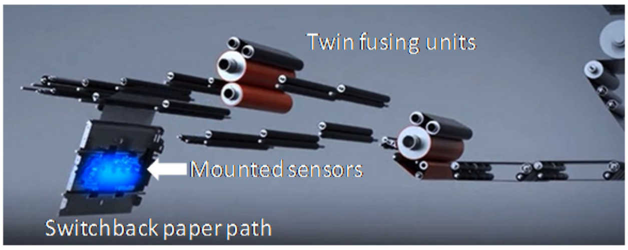

Figure 11. *Mounted sensors.*

Calibrating operation

This section describes the colorimetric measurement process on the imagePRESS C10000VP series for auto gradation adjustment and auto color tone correction.

The top speed of the previous imagePRESS C7000VP model was 70 ipm (single-sided LTR) [1], whereas the new imagePRESS C10000VP model has a top speed of 100 ipm (single-sided LTR). To achieve this spec, the paper delivery speed had to be increased, which presented the following issues for the colorimetric measurement process:

・positional variations in the vertical direction.
(i.e., perpendicular to the paper surface); and
・limits on colorimetric measurement patches .
(size and number of patches, number of sheets).

The faster the paper delivery speed, the larger the positional variations of the test charts will be in the vertical direction, due to shocks from the paper passing / touching transport guides, transport rollers, and backup rollers that operate during colorimetric measurements.

Furthermore, to average the colorimetric measurements within one patch, the faster the paper delivery speed, the larger the necessary patch detection area, provided that the number of samples and the sampling frequency are the same. This means the patch size must be made larger. However, if the patch sizes are made larger, more test charts will be needed for auto color tone correction, which will worsen the usability.

We resolved these issues for the imagePRESS C10000VP series by optimizing the paper delivery speed and making colorimetric measurements with the sensor after the switchback in the switchback paper path that follows the fusing unit.

Conclusions

In this paper, we reported on the development of a small spectrophotometric sensor that can be mounted inside a color printer and detailed the application of technologies to reduce the sensor size and raise its colorimetry accuracy.

The imagePRESS C10000VP series of printers have been equipped with the sensor discussed in this paper, enabling automatic execution of color tone correction that corrects the color balances of compound colors, in addition to conventional single-color gradation adjustment, without requiring user intervention.

References

[1] Mitsuhiro OTA, "Challenge Achievement of High Speed and Image Quality on a Variety of Printing Media -imagePRESS C7000VP-," Journal of the Imaging Society of Japan, 47 No.2 pp.97-103 (2008) [in Japanese].

Author Biography

Shun-ichi Ebihara received his B.E. and M.E. degrees in Material Science and Technology from Waseda University, Japan in 1991 and 1993, respectively. He joined Canon Inc. in 2000 and has been engaged in the development of electro-photography.

