Controller Firmware Technologies for High-speed Color Printers

Hirohiko Nakazato Yoshitaka Nishiyama
Takaaki Hosoda Masahiro Yoshimoto

In recent years, the color printer market has been characterized by two distinct trends. On one hand, there is a growing demand for high-end color printers equipped with high-performance printer controllers. On the other hand, a strong demand has developed for inexpensive color printers, which are seen as replacements for monochrome printers, and cost reduction of printer controllers has also become important.

Oki Data has developed high-speed, Single Pass Color © *1) printers that use tandem engines and is also developing a controller architecture that features superior expandability for both high-end color printers and low-end color printers.

In addition to being installed in general offices, color printers are used as shared printers in network environments and are used for color printing of various document files.

This article discusses various controller firmware technologies. The first section introduces the basic firmware architecture, which uses object-oriented language in a general-purpose, real-time operating system. The second section introduces network processing technologies that support different types of communication protocols and feature superior cost performance as network printers. The third section introduces various color processing technologies that are being implemented in printers ranging from high-end color printers to low-end color printers.

Firmware Architecture

From the viewpoint of the significant amount of printer development manhours and the development period required, the first feature demanded of the controller firmware is scalability so that the firmware can flexibly support a wide range of product configurations.

Another feature that is important in determining the basic firmware structure is the ability to customize the firmware and add functions easily. This feature enables the printer developer to develop multiple printer models concurrently and respond quickly when an OEM destination or a major client demands specification changes or additions.

As shown in Table. 1, the printers to be developed have various combinations of ROM/RAM size, host interfaces (such as IEEE 1284, USB, and network interfaces), page description language (PDL) types, built-in hard disk drive (HDD), and optional devices (such as multi-level paper trays, a duplex printing unit, and a finisher). The firmware must be configured so that it satisfies the requirements of all printer models, in terms of both program size and program functions.

Table. 1 Device configuration examples for individual printer types

Printer type	ROM	RAM	Print speed *a)	PDL	Duplex printing	HDD	Finisher
Color: low end	4 MB	32 MB	12 ppm	Host-based (GDI)	Yes *c)	No	No
Color: middle end	16 MB *b)	64 MB	20 ppm	PCL	Yes *c)	Yes *c)	No
Color: high end	32 MB *b)	192 MB	30 ppm	PCL Post-Script	Yes *c)	Yes *c)	Yes *c)

*a) Color, A4 printing speed
*b) Includes internal font data.
*c) Option

On the other hand, to secure independence from the device specifications of individual printers and to reduce the print processing load in the host computer, developers use a PDL like the PostScript © *2) language or PCL to describe the print data. The firmware must interpret and execute the PDL instructions at high-speed and draw out the maximum print speed from the engine. Especially with high-end printers, companies are waging a fierce printing speed competition, and it is very important to shorten the total printing time, which includes PDL processing by the printer driver on the host computer and the printer.

Described below are the basic structure of the controller firmware for realizing scalable and easy-to-customize color printers and the main components of the basic structure. Also explained is the firmware's "pipeline" process that handles PDL processing and accelerates the printing speed.

(1) Basic Structure of Controller Firmware

The basic functions of the controller firmware include interpreting and editing the print data described by the PDL into page units, generating page data that can be

*1) Single Pass Color is a registered trademark of Oki Data Corporation.
*2) PostScript is a registered trademark of Adobe Systems Inc.

output by video, sending the print data together with print control commands to the engine, and controlling the print operations of the entire device.

Printers that are connected to networks must also have functions such as supporting various communication protocols, performing remote monitoring of the printer status, tracking the usage status of consumables, and letting the user know when consumables must be purchased.

We considered the demands for adding these new functions and adopted a hierarchical structure that stresses function expandability for the controller firmware. This structure is shown in Fig. 1.

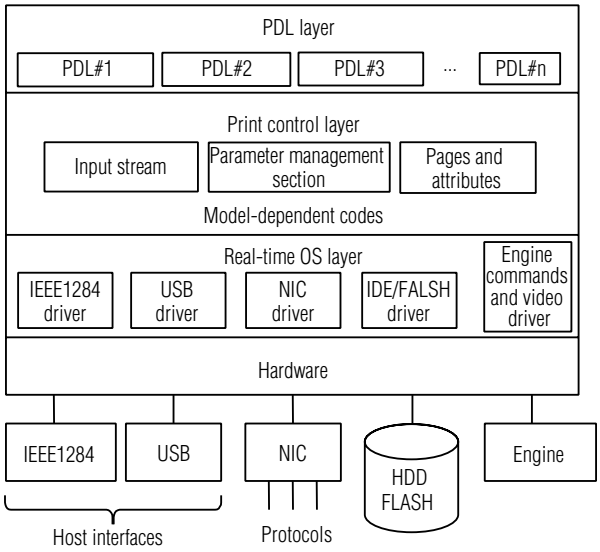

Fig. 1 Hierarchical structure of controller software

The operating system (OS) layer consists of a real-time OS kernel, device drivers, file systems and standard libraries. This layer abstracts the interfaces with hardware devices (controller and engine) to assimilate the differences of each model. The differences in the installed host interfaces are handled by adding and deleting device drivers.

Using the print control layer, the number of functions installed in the PDL layer can be minimized and, to facilitate addition or deletion of PDLs, as much as possible PDL-independent, common functions are provided, such as those described below [1)].

- Receive print data from the different host interfaces (devices).
- Control the print sequence in the engine and send video data that is synchronized with that print sequence.
- Report warnings and errors related to remaining levels and service life of consumables, such as the toner and the imaging unit, paper jams, paper out situations, and size mismatches.
- Display the printer status on the operator panel and via the network management utility, and read and change menu setting values (parameters).
- Perform services including data spooling using the HDD, collated printing, authentication printing, confirmation printing, and direct printing.
- Recognize the PDL describing the print data (job), allocate the print data to the appropriate PDL process system, and identify the end of the print data.

The print control layer uses an object-oriented design method and language to realize the diverse functions described above, resulting in a structure that emphasizes reusability, expandability, and model-independence. This layer clearly separates model-independent sections and model-dependent sections and minimizes model dependence to facilitate concurrent development of multiple models and migration to new models.

The read destination (for example, an individual host interface, HDD/Flash, or ROM) of the print data, the page data format and generation procedure for each PDL, and the menu setting values are sections that differ substantially depending on the model (device configuration). To assimilate these differences, the print control layer has an input stream, page objects and page attributes, and a parameter management section as its main components. These components clearly separate model-independent sections and model-dependent sections, and assimilate the device configuration differences of each model by replacing the model-dependent sections that are installed.

(2) Input Stream

The controller firmware assimilates differences in the host interface receiving the print data and the communication protocol by standardizing an interface called the input stream. This input stream is designed to handle print data spooled (stored) in the HDD and print data stored in ROM in the same way as print data received from the host interface.

By introducing this input stream, we have been able to get the receive data processing section of the print control and PDL layers to read print data without having to account for the host interface receiving the print data or the protocol. The input stream also facilitates the addition of new host interface devices and communication protocols, and facilitates modification of the device configuration through component selection or elimination.

(3) Page Objects and Page Attributes

PDL differences result in differences in the holding method of generated page data, the data generation timing, and memory management system. The controller firmware uses page objects and page attributes to assimilate such differences among PDLs and to create a common printing process (print control layer) for each page.

For page objects, print start and print end are defined and the interface, etc. for data acquisition is specified. Specifications such as the paper type and feeding tray for each page are provided as page attributes to each page object.

These page objects and page attributes allow the print control layer to print generated pages without having to deal with PDL differences.

(4) Parameter Management Section

Printers have many parameters that can be changed through operator panel operations and commands assigned to print data. These parameters include print operation instructions, host interface settings, and mechanical settings. A color printer has a few hundred parameters.

Parameters are managed by the parameter management section. The print control layer and the PDL layer specify various settings to this parameter management section and do not access the engine or PDL contents directly. The parameter management section allows the controller firmware to be independent of parameter presence/absence and of parameter differences of each model.

(5) Increased Speed through Job Overlapping

The PDL layer interprets and expands print data to generate page-unit video data and passes that data to the print control layer. The print control layer then sends the page-unit video data to the engine for print processing. After interpretation and expansion processing of the current print data (job) is completed, the PDL layer should start processing the next job without waiting for the engine to finish printing the current job. This method is called job overlapping and it results in increased speed for the entire printer.

The print control layer therefore manages the memory between PDLs so that even if the current job and the next job use different PDLs, it can start PDL processing of the next job without having to wait for printing of the current job to end. This feature enables the engine to continue printing at its normal performance speed without stalling at job boundaries (PDL switching), even if the host computer sends a sequence of jobs that use different PDLs.

(6) "Pipelining" of Color Image Processing

Color image processing includes data compression and decompression, image expansion and reduction, halftone processing, and color matching. Generally, these color image processes create a bottleneck with respect to processing speed in the PDL processing system because large amounts of data must be handled. The controller achieves high speed processing by delegating this color image processing to hardware on a special LSI chip. The PDL processing system also divides each page into multiple bands and uses a pipeline to carry out the expansion process in band units. This way, the controller is able to maximize the parallelization of software processing by the CPU and hardware processing by the special LSI (Fig. 2).

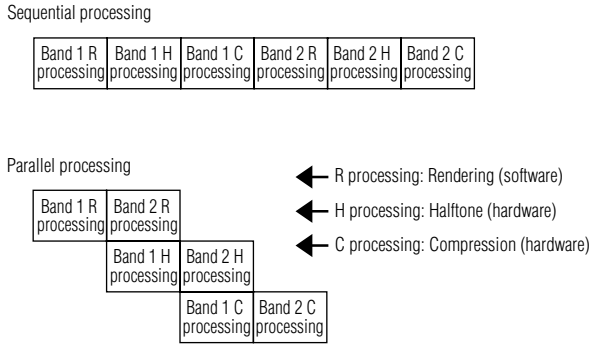

Fig. 2 Parallelization of color image processes

Network Processing Technology

Printer networking has progressed in recent years, and printers used in offices today generally support network functions as standardfeatures.

Oki Data regards function expandability as important in our high-end color printers. We have therefore been developing and providing card-type network boards (card-type NIC) that are equipped with a CPU. For our low-end color printers, we have developed a new method (embedded NIC) in which the CPU of the printer unit controls network functions directly. The embedded NIC has helped us realize both low cost and high performance in our low-end color printers.

This section focuses on the embedded-type NIC while comparing the characteristics of both methods.

(1) Network Protocols

Fig. 3 shows the main network protocols (a set of rules for communication) that are supported by Oki Data's color printers. The communication layer and the application layer together are called the protocol stack.

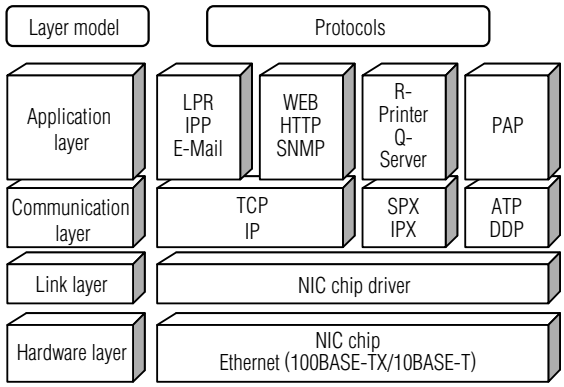

Fig. 3 Relationships among network protocols

The card type NIC and the embedded NIC each support various protocol stacks for printing and setting up TCP/IP, Netware® *3), and AppleTalk® *4) systems.

(2) Configuration of Network Processing

The card type NIC implements network functions using a board equipped with a protocol stack, as shown in Fig. 4.

*3) Netware is a registered trademark of Novell, Inc.
*4) AppleTalk is a registered trademark of Apple Computer, Inc.

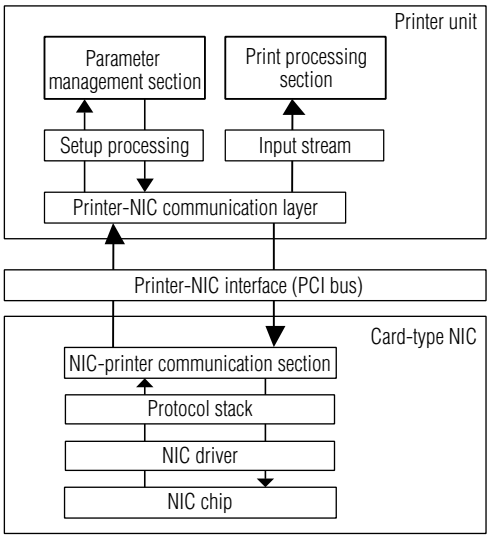

Fig. 4 Block diagram of card-type NIC

In this configuration, communication between the printer unit and the NIC takes place through a PCI bus, and print data and setup data are each processed independently.

The embedded NIC, on the other hand, employs a method in which the printer controller CPU controls the NIC chip directly and a configuration in which the protocol stack is incorporated into the printer unit, as shown in Fig. 5.

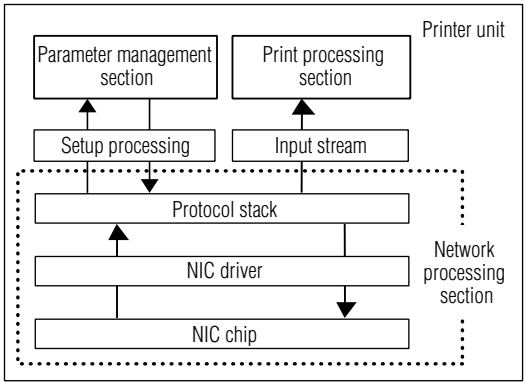

Fig. 5 Block diagram of embedded NIC

We therefore developed a new protocol stack and a new NIC driver.

For print system processing, we adopted a method that accesses the input stream directly. For processing related to accessing and changing status and setting information, we converted the setup processes of the card-type NIC into libraries to maximize the use of the process resources that have been established by the card-type NIC.

(3) Performance

To realize network processing with the printer unit CPU, the embedded NIC must execute print processing and network processing efficiently.

Since print processing and network processing operate through multitasking, the task priorities have been carefully arranged so that the processing tasks can operate optimally.

In addition, we have realized high-speed reception performance by reducing the amount of multicast and broadcast packet processing.

(4) Update of network processing firmware

To support the latest protocol stacks, we needed to allow the network processing firmware to be updated separately from the printer unit firmware.

In the embedded NIC, we developed a new program-linking method so that the network processing firmware can be updated.

(5) Latest network trends

Concerning network printer trends, here we will discuss wireless LANs and security.

1) Wireless LANs

Recently, wireless LANs have become very popular even in companies. The reasons for the popularity include merits such as the fact that wiring of cumbersome network cables becomes unnecessary and work efficiency can be improved both in or out of the office if a notebook PC is used.

Wireless LANs use several protocols, and the main protocols are shown in Table 2.

Table. 2 Main wireless LAN protocols and their performance

Protocol	Maximum speed	Used frequencies	Modulation method
IEEE802.11a	54 Mbps	5.15 - 5.25 GHz	OFDM
IEEE802.11b	11 Mbps	2.4 - 2.497 GHz	DSSS
IEEE802.11g	54 Mbps	2.4 - 2.497 GHz	OFDM
Bluetooth1.0	1 Mbps	2.4 - 2.497 GHz	FHSS

Oki Data is introducing as recommended products external products for the IEEE 802.11b protocol, which is currently the most widely used protocol. We plan to develop products that support wireless LANs in the future.

2) Security

In recent years, the cases of illegal access and break-in through a network have increased and developed into a social problem. In addition, the cases of attack by damage-causing viruses and worms have increased. Unless security measures are taken when a wireless LAN is used, the problem of illegal access by a third-party can occur easily because connection to the LAN is possible from any communication-enabled area, even an outdoor location. Therefore, the industry's consciousness toward "security" has been raised.

To enhance the security of network printers, Oki Data uses standard protocols for authentication and encryption. We also plan to develop products that support user authentication and encryption for printer setting changes, as well as encryption functions for print data.

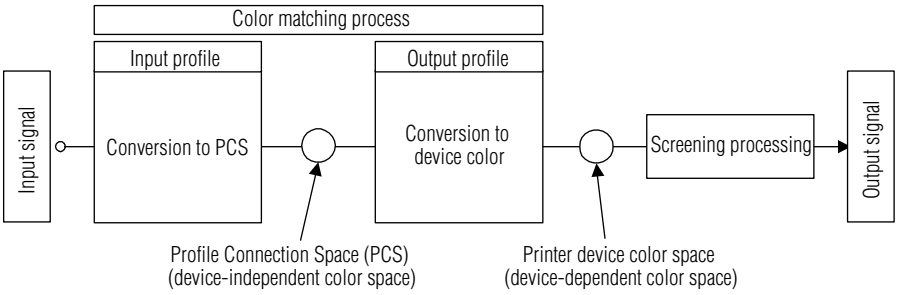

Fig. 6 Standard color processing structure of printers

Color Processing Technologies

This section describes the optimization of color processing technologies from the viewpoint of color processing with each PDL type supported by Oki Data's color printers.

(1) Color matching process and screening process

With color printers, color image data sent from the host computer and expressed in RGB or CMYK is processed and printing is done with 4-color CYMK toners.

The color-matching process calculates the optimal color combination proportions for printing the input color data with the 4-color CMYK toners of the printer. The basic functions demanded of the color matching process do not change from high-end printers to low-end printers. However, Oki Data's high-end printers support color processing for the PostScript ® standard, which is the page description language widely used in the desktop publishing (DTP) and printing fields.

The screening process uses pseudo-gradation expression methods such as dithering to generate color image data that the print engine can print, and the method that best matches the characteristics of the print engine must be selected. In recent years, the amount of generated image data has increased as a result of higher printer resolutions, and high-level processing capabilities are being demanded of color printers.

Fig. 6 shows the standard color processing flow of a color printer. The input data is converted from its color space to a device-independent color space by means of the color matching process. The data is then converted to a device color space suited to the printer characteristics and becomes CMYK color data. The screening processing converts each CMYK color data to print image data that can be printed by the print engine. The color matching process converts the data to the target device color space through the device-independent color space, based on data describing the characteristics of the printer device. Data that describes device characteristics is called a profile, and the color space that has the intermediary role in this process is called the profile connection space (PCS).

For characters and graphics, which are often colored in a uniform color, the load placed on the color matching process is relatively small. However, for images, the load is large because images contain an extremely large volume of color data. An extremely large load is placed on the screening process to output print data at the print resolution supported by the print engine. Therefore for high performance of high-speed color printer controllers, it is very important that the color matching and screening processes for image data be enhanced by means such as assigning the processing to hardware.

(2) PDL color workflow

1) PostScript ® color workflow

Figure 7 shows the color workflow of the PostScript ® language. The PostScript ® language is used mainly in the specialized applications of the DTP field and it can handle color spaces that are not dependent on the OS. These applications can handle CMYK data, they have a color matching engine, and they can send to the printer CMYK data that has been color-matched based on the printer profile information.

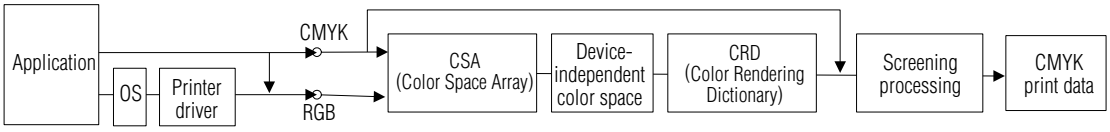

Fig. 7 Structure diagram of PostScript ® color processing

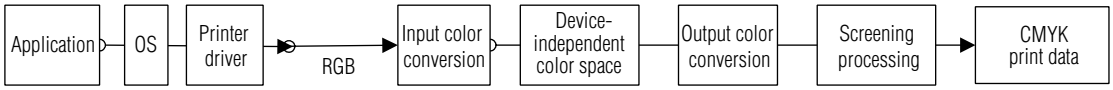

Fig. 8 Structure diagram of PCL color processing

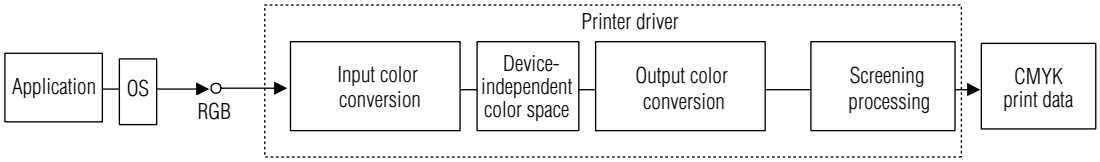

Fig. 9 Structure diagram of host-based color processing

2) PCL color workflow

Fig. 8 shows the PCL color workflow. Although PCL supports several input color spaces, but essentially RGB is used because of the relationship of the host computer to the OS and the application.

3) Host-based color workflow

Fig. 9 shows the color workflow of a host-based printer.

Although the basic workflow is the same as in PCL color printing, the difference is that the printer driver of the host computer performs the color processing.

As described above, it is important that the color processing of high-speed color printer controllers possess scalability and be able to reproduce consistent colors that are not affected by differences in the PDL method or the print engine.

Oki Data's high-end color printers support PostScript® color processes. We are working on optimizing the firmware so that it can effectively use hardware which accelerates color processing, such as image processing LSI chips, and the hardware resources of high-performance CPUs.

In addition, for our mid-range color printers, we have designed them to maintain high speed color processing by balancing the CPU performance and the image processing LSI chip.

For our low-end printers, we have developed host-based color processing technologies that use the high-performance processing capabilities of the host computer while realizing maximal cost-effectiveness.

Summary

In this article, we described the basic architecture, network processing technologies, and color processing technologies for high-speed color printer controllers from the firmware viewpoint.

In the future, we will continue to develop firmware with superior expandability so that we can manufacture color printers that feature high-speed printing, advanced functions, and low cost.

References

1) Nagata et. al.: Oki Technical Review No. 185, "High-speed Controller Technology for Single Path Color © Printers," Vol. 68 No. 1, pp.128-131, January 2001.

Authors

Hirohiko Nakazato: Oki Data Corp., Controller Development

Center, Software Development Dept.-2, General Manager

Yoshitaka Nishiyama: Oki Data Corp., Controller Development

Center, Software Development Dept.-2, Manager

Takaaki Hosoda: Oki Data Corp., Controller Development Center, Software Development Dept.-2, Manager

Masahiro Yoshimoto: Oki Data Corp., Controller Development Center, Software Development Dept.-2, Manager