Digital Color Printer for Photographic Paper Using LED Arrays

Yoshitaka Ohta and Masayuki Inai
Konica Co. 2970 Ishikawa-cho, Hachioji-shi, Tokyo Japan

Abstract

We have developed a digital color printer for photo-graphic paper using LED arrays. Said array has 96 LED elements for each color of red and green, and 48 elements for blue on a copper base. The distance between each LED elements is equal to two pixels in the main-scanning direction, and one pixel in the sub scanning direction. Two elements are mounted on the same main-scanning line. (Fig.1)

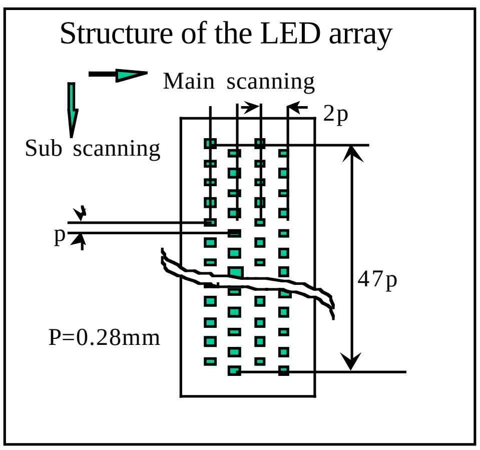

Figure 1. Layout of the LED elements

The image of the array is focused on the paper through a lens at a magnification ratio of about 0.25(the pixel size on paper is 70 microns).

All LEDs are simultaneously driven by constant current drivers and modulated by digital pulse-width. There are 128 PWM steps for each element, and the pixel on the photographic paper is exposed 24 times, as a result, there are 3072 steps of the exposure.

Our recording system has two feed back loops, one loop utilizes photo-diodes to measure and compensate for the power of each LED, and the other loop utilizes a densi-tometer to compensate for the sensitivity and the tone curve of the photographic paper and the chemical development.

Using these technologies, our system is extremely stable, and the image quality meets the stringent requirements of professionals.

The Recording Mechanism

Figure 2 shows the recording mechanism. The photo-graphic paper is loaded onto the recording drum from the supply magazine after being cut to the specified length by a rotary cutter.

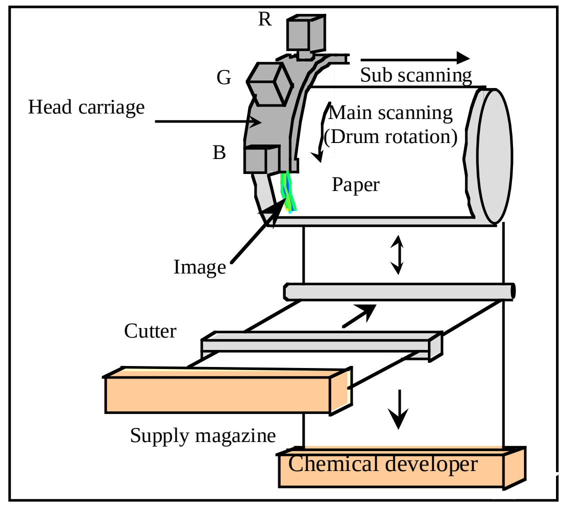

Figure 2: Recording mechanism

The main scanning is done via the rotation of the recording drum at a rate 600RPM. The recording drum is driven via a belt by using DC-brush-less motor controlled by a PLL.

The sub-scanning is achieved by moving the head-carriage via a 5-phase stepping motor. The rotation of the stepping motor is slowed down by a two stage pulley system. Finally, the head-carriage is driven with a stainless steel belt. The sub-scanning speed is 0.7, 1.4 or 2.8mm/sec (respectively 96, 48, 24 multiple exposures).

The sub-scanning speed is automatically selected according to the sensitivity of the paper in the supply-magazine.

After image recording, the paper with a latent image is sent to the chemical developer.

The System Configuration

Figure 3 shows a system block diagram. The host computer sends the image data to the image memory through the SCSI I/F. The System controller starts printing after the transfer of an image.

The Image Memory

There are three purposes of the image memory. One is to increase the speed from the host computer using idle times of the SCSI-I/F during recording. Since the image memory is designed as a ring buffer, the host can send image data to the printer whenever the memory is not full.

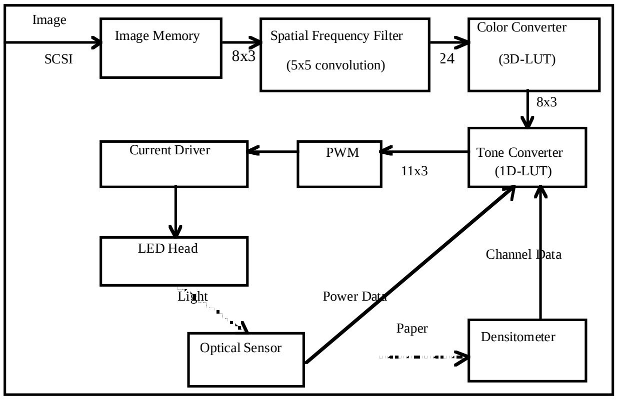

Figure 3: System block diagram

The second purpose is to avoid pauses during recording because of delay of data from the host. If the transfer speed from the host computer is slower than the printing speed, the printer must wait for data. In that case, the effective exposure for photographic paper is not sufficient because the exposure effect on the photographic paper dissipates, as a result, there is line noise on the image.

The last purpose is to save the host's CPU-power and disk spaces. It is not required to orient or expand images in the host computer, since the memory controller is able to print images in any orientation at half or full resolution.

The standard volume of the image memory is 96Mbytes; 128Mbytes is an option.

The Image Processing

The image processor executes the spatial frequency filtering with a 5x5 convolver. This filter compensates for the random light distribution of LED elements and conserves CPU-power of the host computer to produce images at desirable level of sharpness.

It also processes color conversion through a 3-dimentional color-look-up-table (3D-LUT), and it also processes tone conversion through a 1-dimentional looking-up-table (1D-LUT) by a pipelined hardware.

Said LUTs are used to adapt to many kinds of papers and transparency films, and to adapt to the preferred color balance of each operator.

After these processes, the image data is sent to the PWM circuit where the data is converted to exposure time. The constant current driver controls each LED element to expose the paper according to the PWM signal.

The Compensation

The printer has three optical sensors for each color. During warm-up of the chemical developer, the system controller moves the heads to the sensor position, activates the LEDs, access the data of optical power of each group(group refers to LED elements that expose the same point on the paper, see Fig.4). Then it compensates for the power of each group by setting the LUT for each element.

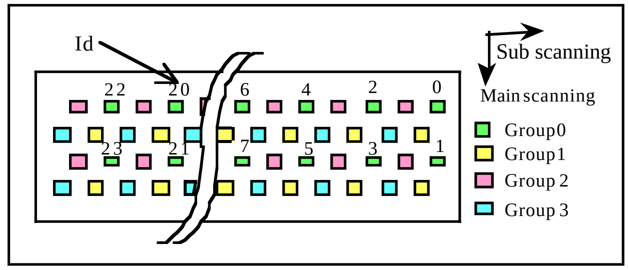

Figure 4: The group definition of each element

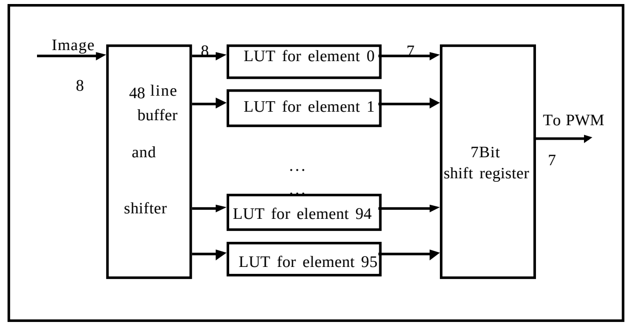

Figure 5: Structure of the 1D-LUT

The input of each LUT is 8bits and the output is 7bits. This means that these LUTs work as 8 bit input and 11.5 bit output LUT, with 24 multiple exposure, see Fig. 5.

The system can set all LUTs individually for all elements, but it takes much more time than group compensation to access and calculate the compensation data. The 1D-LUT for each element in one group is set to be as identical as possible.

Each LUT in one group is defined as follows:

$$L = D \;/\; Q$$
$$R = D \;\%\; Q$$
$$C = \begin{cases} 0 & \text{if } R <= Id \\ 1 & \text{if } R > Id \end{cases}$$
$$O = L + C$$

Where,
Q : Number of non-damaged elements (24)
Id : Designated number of the LED element in the group(0..Q-1)
D : Output value of groups of 24LUTs (0..3071)
O : Output exposure level according to level D (0..127)

This means that even if some elements are damaged, the system compensates for those defects by using other non-damaged ones. If damaged elements exist, subsequent Ids are re-identified. Even if the system can not detect the damage LEDs, it can detect them due to the lack of optical power of the group, and can compensate for the group power, although there are small drops on the tone curve.

Figure 6 shows an example of a normal tone curve for Konica paper QAA7. The maximum value of the output of the 1D-LUT is limited to about 2000 to compensate for the decrease of the optical power.

The ratio of the decrease is according to the activated time and the current. When the current is 2 times higher than standard, the maximum ratio of the decrease is 50% after 2000 hours of power activation.

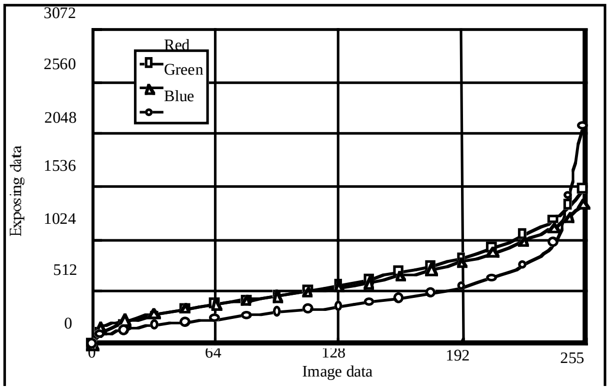

Figure 6: An example of normal 1D-LUT curve

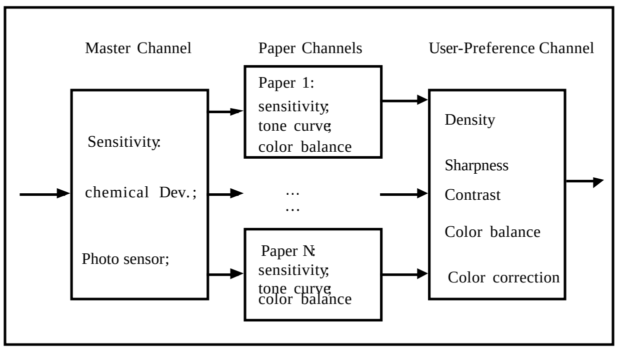

Figure 7: The theoretical channels

The System has three kinds of theoretical channels. One is a paper-channel, another is master-channel, and still another is a user-preference channel. Fig. 7 shows these channels.

The master channel is used to compensate for the daily variations of the chemical developer, and for the minor error of the photo sensors. This channel controls the sensitivity constant and 1D-LUT.

The paper channel is used to compensate for the paper characteristics of the tone curve and color balance, this channel regulates the combination of 1D-LUT and 3D-LUT. A paper channel is automatically selected from the several registered ones according to the code on the supply magazine which distinguish the kind of medium (such as type, size, etc).

The user-preference channel is used for setting the image quality according to the content of images and to the preferred quality of operators. Selectable parameters are density of each color, contrast, saturation of color and sharpness. This is realized by a combination of the filtering module, the 3D-LUT and the 1D-LUT.

Timing Generation

A PLL (phase locked loop) module generates a recording timing and the base clock for the digital pulse width modulation (about 22MHz) from signals of an encoder connected to the recording drum. The PLL removes an influence of the rotation error of the motor which drives the drum. Even though the motor itself has its own another PLL, there is still not enough stability.

Multiple Exposure

The big problem of recording images with light source array is patterned line noise on the recorded images. This noise is caused by the variation of power, pitch, size and optical wave-length of light sources.

Figure 8 shows the spatial frequency characteristics of the noise on the single exposure image. There is noise sensed by human eye in the low frequency area. Since this noise is caused by many factors, even if we completely compensate for the optical power of each element, we can remove no more than 30% of the noise.

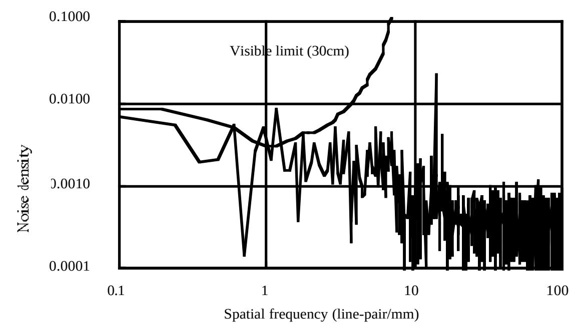

Figure 8: The spatial frequency characteristics of the non-multi-exposed image

We remove said noise by using multiple exposures.

Our array has 96 LED elements. The number of elements is determined from the specification of recording time (120 sec for 14x17 inches) and the sensitivity of the material, the optical power of the LED element, the refractive power loss of the optical lens and the functional-life of the light sources.

The number of multiple exposure is determined from the sensitivity of the human eye.

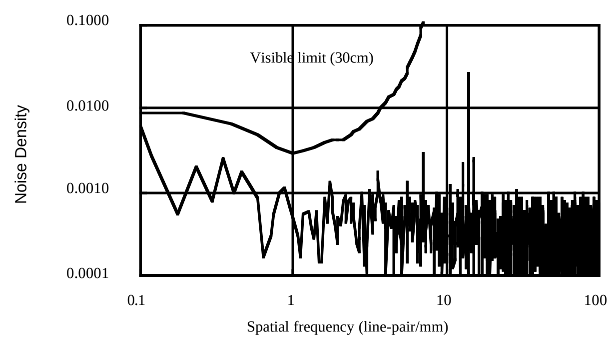

Figure 9: The spatial frequency characteristics of the multi-exposed image

We can completely remove noise by using all 96 LED elements to expose an individual pixel. But in that case, we need faster drum speeds and a faster PWM circuit (about 80MHz) to use all LED elements during a specified recording time (120 sec for 14x17inch image).

To slow down the base clock and the drum speed, we select 24 multiple exposures. It means that we record 48 lines during one drum rotation, and head moves 4 lines in the sub-scanning direction during that time.

In this case, the spatial frequency of the noise is higher than 45 line-pairs per inch. The sensitivity of the human eye at this frequency is rather low and the noise level becomes less than about 1/5.

Figure 9 shows the spatial frequency characteristics of the noise of the image by 24 multiple exposure without power compensation.

We can see that the noise level is lowered and the spatial frequency of the noise peaks is increased.

Conclusion

We have developped a very stable, high quality and cost competitive digital color printer for photographic paper by using the new channel architecture and the multiple exposure technicques for LED arrays.

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