A Novel Digital Color Printer Based on Silicon Microdisplay

K. C. Lee, H. L. Cheung, C. S. Chan, H. C. Huang and H. S. Kwok
Centre for Display Research & Department of Electrical and Electronic Engineering
The Hong Kong University of Science and Technology
Clear Water Bay, Hong Kong

Abstract

We have developed a novel digital color printer using silicon microdisplay as the image generator. The digital image data were written into the silicon microdisplay in color sequence and projected onto a Polaroid 500 film for additive color printing. 30-bit full color was achieved through the color and field sequential exposure technique. Resolution of over 300 color pixels per inch was obtained with the silicon microdisplay of 1024 x 768 pixels.

Introduction

In recent years, there are a number of digital still camera emerged. While most of the users enjoy these cameras making electronic copies of images they captured, many of them want color hardcopies like traditional photos they can make from traditional cameras. There are many printing technologies available to print in a colorful way.[1,2,3] but probably none of them can achieve the quality of photos, which have approximately 600 pixel/inch and 256 halftone levels.[4] To produce such excellent quality hardcopy similar to traditional photos from images taken by digital still camera or other images stored in electronic form, a better method has to be used.

Silicon microdisplay is an emerging technology for projection and virtual reality display applications.[4,5] The silicon microdisplay is a marriage of very advanced silicon VLSI microelectronics and liquid crystal display (LCD) technology. Whereas, the silicon VLSI circuit generates electronic image and the LCD converts the electronic image into optical representation. The advantages of silicon microdisplay are high integration, high resolution and low power consumption. Very sophisticated display drivers and very fine pixels can be integrated together as a self-contained and high-resolution display. The monolithic integration of drivers into the display also helps simplify the interconnection and packaging problems associated with the display system. As a result, the silicon microdisplay is very suitable for portable display applications where small physical size and low power consumption are decided advantages.

In this paper, we describe the development of a high-resolution digital color film printer using the silicon microdisplay as the image source for exposure. The silicon panel of 1024 x 768 pixels and 6-bit digital gray scale was designed and fabricated by a custom CMOS process.[6] Color and field sequential technique was applied to increase the 6-bit monochrome display to a 30-bit full color display. The image was projected onto a Polaroid 500 film, which has an image area of 3" by 2", for additive color printing.

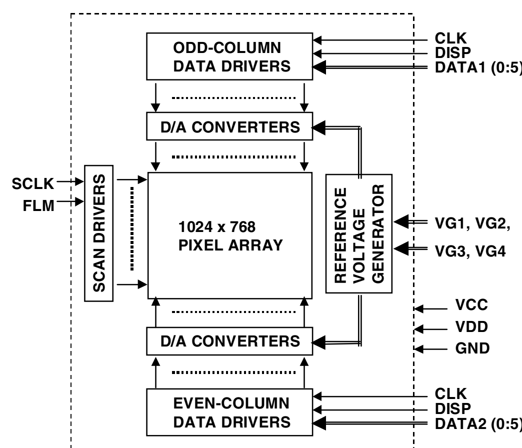

Figure 1. Functional block diagram of the silicon panel

Silicon Microdisplay

The heart of this printer is the silicon microdisplay, which takes electronic images and converts to optical images for photographic printing. The silicon microdisplay is a highly integrated display device, which integrates display drivers and fine pixel array together. Figure 1 shows functional block diagram of the XGA silicon panel. The data drivers have 6-bit resolution. 6-bit digital pixel data are shifted in series to the data drivers and transferred in parallel to the D/A converters where D/A conversions are performed. Gamma-correction circuitry is integrated onto the silicon panel in order to generate 64 reference voltages for the

D/A conversions. Fine tune of the reference voltages is possible through the external gamma correction voltages VG1, VG2, VG3 and VG4.

The display panel has 1024 x 768 spatial resolution in mosaic arrangement. The pixel pitch is 13.8μm and the fill factor is 91%. Figure 2 shows photograph of the silicon microdisplay in action. The data drivers are on the top and bottom, the scan driver is on the left, and the pixel array is in the center.

Figure 2. The silicon microdisplay in action

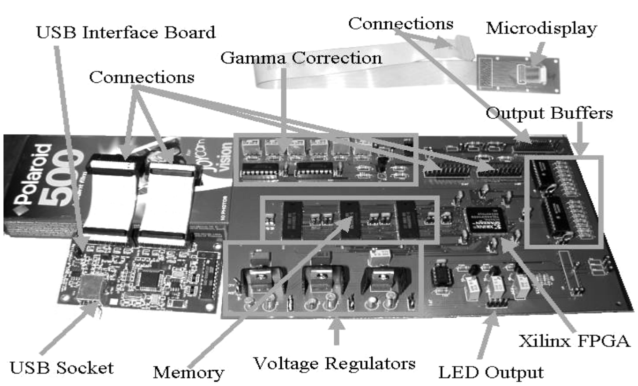

Figure 3. Research prototype of the digital color printer

Color Printer Prototype Driver Board

Figure 3 shows a research prototype of the digital color printer driver board. The driver board has a FPGA as the core component, which control the data flows and produce control signals for the microdisplay. There are three SRAM ICs, which uses as the buffers to store the image transmitted through the Universal Serial Bus (USB) interface before they can be written onto the microdisplay. The SRAM ICs are essential to this driver board. Without the memory ICs, the color cannot be reproduced on the microdisplay using the color-sequential and field-sequential technique, which requires data to be processed and output to microdisplay for several times.

A Xilinx SpartanXL FPGA XCS10XL-4TQ144C was used to implement the logic control. The equivalent gate count was around 3000 and 80 I/O pins were used. The configuration data of the Xilinx FPGA for different image resolutions were stored in EEPROM. In-circuit reconfiguration of the Xilinx FPGA for different resolutions was possible. Gamma correction was also implemented in the printer driver board by changing the reference voltages input to the microdisplay. The voltage regulators onboard ensures simple while stable power supplies for the whole circuit board as well as the microdisplay. The output buffers ensure correct signals output to the microdisplay through the long cable.

Optical System

A 3-color-in-1 LED is used as the light source, which is placed at 38mm from the collimating lens with diameter of 25mm and 38mm in focal length. The collimated light is then directed to the microdisplay through the Polarizing Beam Splitter (PBS), and the modulated light is reflected to the aspherical projection lens with 30mm in diameter and 30mm in focal length. With the aspherical lens placed at 36mm from the image source (microdisplay) and the Polaroid 500 film placed at 180mm on the other side of the projection lens. The image loaded on the microdisplay is enlarged for five times to fit on the 3” by 2” image area of the film.

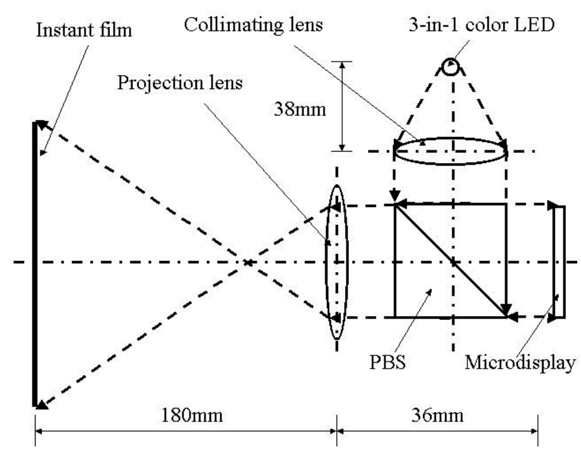

Figure 4. The optical system

Color and Field Sequence

In order to achieve full color and good gray scale, color and field sequential technique are employed as shown in Figure 5. Without these techniques, only monotonic image hardcopy with 6-bit grayscale can be produced by the printer. In fact, the color sequential technique is simple. The red (R), green (G) and blue (B) digital images are first stored in the memory. Thereafter, the R, G and B data are written into the microdisplay in sequence, namely R sub-frame, G sub-frame and B sub-frame. There are three phases in each R, G or B sub-frame. The first phase is the data loading phase, which the corresponding R, G or B sub-frame is loaded into the microdisplay. The second phase is the LC response phase in which the LC responds to the loaded sub-frame data. The third phase is the LED illumination phase in which the corresponding R, G or B LED is turned on to illuminate the microdisplay and project the image onto the Polaroid instant film.

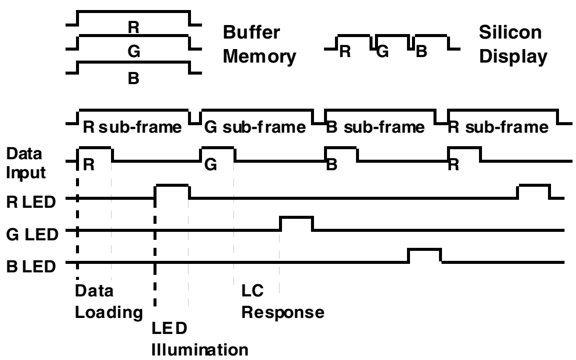

Figure 5. Schematic of the color and field sequential technique

To enhance the number of gray scale that the microdisplay can output, multiple frames of processed data from selected bit-planes are output sequentially as fields of color frames, which are called field-sequential technique. With this color and field sequential driving scheme, the 6-bit monochrome silicon microdisplay was turned into a 30-bit full color display.

Printing Process

To produce a colorful hardcopy, the printer takes the image data from the notebook computer or PC through a USB interface and stores the data into a buffer memory. Thereafter, the data are written to the microdisplay in color and field sequence for corresponding color exposure on the Polaroid instant film. The image loading is the most time consuming part for the printing as no compression method is employed for the transmission in this printer prototype. It takes about 50 seconds to load the entire image from the PC into the buffer memory. To achieve 10-bit gray scale on the 6-bit microdisplay, field-sequential technique is used, where each color image was divided into 16 fields and written to the microdisplay in sequence. It takes from 1/32 second to 4 seconds for each field exposure, which is programmable through the software interface.

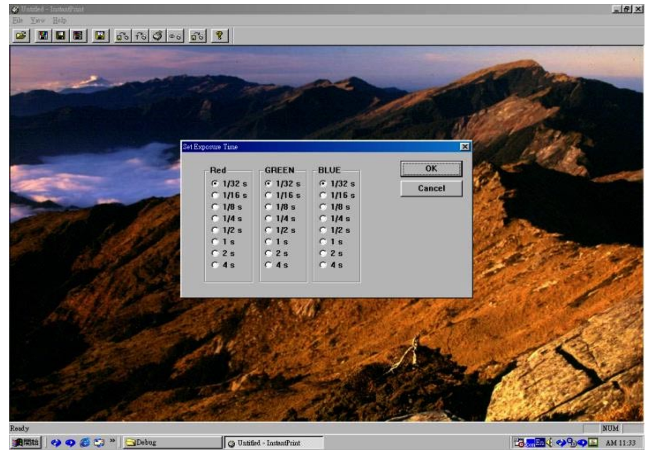

Figure 6. Exposure setting by software

Normally, 1/8 second is required for one field exposure, therefore, 2 seconds is needed to complete the 16 field exposures for one color. As a result, the printer spends 6 seconds to print three colors and it takes about 1 minute for one print (including the data loading time). As the image is stored in SRAM, no retransmission is needed for producing multiple hardcopies of the same image.

The printer prototype consumes about 3W during the printing operation. The printer driver attributes for most power consumption and drains 2.5W for 60 seconds, or 150Wsec per print. The silicon microdisplay consumes 400mW for 6 seconds during photographic printing, or 2.4Wsec per print. The LED consumes 170mW for 6 seconds, or 1.0Wsec per print. Figure 7 shows the preliminary printing sample. Figure 6 shows color coordinates of the printing sample. NTSC comparable color saturation was achieved.

Figure 7. Preliminary sample

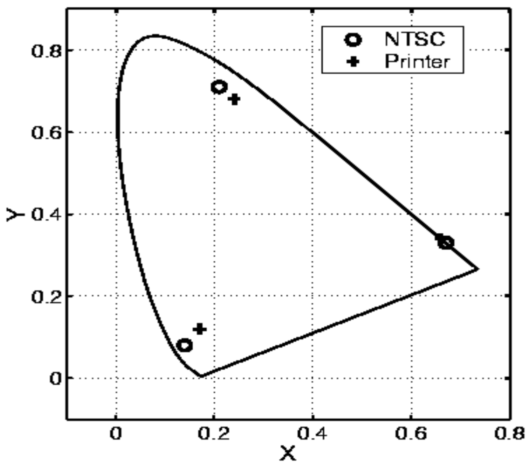

Figure 8. Color map of the printing sample

Producing the Best Color

To get the best color from this printer, a lot of calibration can be made. First, the microdisplay itself features gamma correction by calibration of the reference voltages, which allows produced color in a correct, distinguishable scale. Second, the printer circuit board provides three sets of such reference voltages adjustment unit for the red, green and blue exposure individually, which can minimize the error made by incorrect gamma correction for different colors and causing bad grayscale. Third, the printer allows the exposure time for different color to be set by software, making the film getting correct exposure time for different color frames. Finally, the current flow through the LEDs can be fine calibrated separately, which further minimized the chance of making incorrect color.

Since the printer uses no ink or any dyes to fix onto any paper, there is no chance to have any problem as other kind of color printers, which usually related to the methods of mixing the colors ink or dyes, which causes lower color quality.

Printer Resolution

As the printer output the hardcopy by exposing the image loaded on the microdisplay to the instant film, the printer should be able to produce any wanted pixel per inch by changing the magnification of the image projected onto the instant film. This could be easily done by changing the position of the lens and the instant film. However, owing to the characteristic of the instant film used, the resolution usually may not achieve high value for high contrast content. If high resolution with high contrast color hardcopy has to be made, a better recording medium can be used instead of Polaroid 500 film. In fact, the printer prototype can be easily modified to be a traditional photographic film writer, which can convert digital image captured by digital cameras to traditional photographic film.

Conclusion

In conclusion, we have developed a novel and highly integrated digital color printer. Table 1 summarizes specifications of this printer prototype. The printer utilized a silicon microdisplay as the image generator and printed a whole frame of image onto the Polaroid 500 film in color sequence. Field sequential technique was applied to increase the gray scale limited by the data driver of the microdisplay. 30-bit full color of NTSC comparable color saturation was achieved. With the XGA image printed onto a 3" x 2" area, a resolution of more than 300 color dots per inch was also demonstrated. The printer consumed about 7W during the printing and each print required less than 1 minute to complete. We believe this portable, low power and high-resolution digital color printer is a perfect accessory for notebook computers and digital cameras.

Table 1. Specifications of the printer prototype

Parameter	Value
Resolution	1024 H x 768 V
Pixel Size	13.8µm
Aperture Ratio	91%
Pixel Arrangement	Mosaic
Array Area	14.1mm H x 10.6mm V
LC mode	Reflective MTB mode
Contrast Ratio	100:1, typically
Field of view	20°
Color	30 bits
CIE Coordinates	Red: x = 0.66, y = 0.34 Green: x = 0.25, y = 0.68 Blue: x = 0.14, y = 0.12 White: x = 0.31, y = 0.32
Driving Scheme	Color and field sequence
Power Consumption (per print)	150Wsec Printer driver 2.4Wsec Microdisplay 1.0Wsec LED

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Biography

K. C. Lee received his BEng degree in computer engineering from the Hong Kong University of Science and Technology (HKUST) in 1999. He is now working towards MPhil degree at HKUST.

H. L. Cheung received his BEng degree in Electrical and Electronic Engineering from the Hong Kong University of Science and Technology (HKUST) in 1999. He is currently working towards MPhil degree at HKUST.

C. S. Chan received his BEng degree in Electrical and Electronic Engineering from the Hong Kong University of Science and Technology (HKUST) in 2000. He is currently working towards MPhil degree at HKUST.

H. C. Huang received his BS and MS degrees from National Taiwan University in 1982 and 1984, and PhD degree from University of Washington in 1991, all in Electrical Engineering. He has been an assistant professor at the Hong Kong University of Science and Technology since 1991. He is a member of Society of Information Display (SID).

H. S. Kwok received his BS degree in Electrical Engineering from Northwestern University in 1973, and MS and PhD degrees in Applied Physics from Harvard University in 1974 and 1978, respectively. From 1978 to 1980, he worked at the Lawrence Berkeley Laboratory as a research associate. From 1982 to 1992, he was with the Department of Electrical and Computer Engineering, State University of New York at Buffalo, where he was a Professor since 1985. He joined the Hong Kong University of Science and Technology in 1992. Prof. Kwok is a fellow of American Optical Society and senior member of IEEE.