Tunable Resolution and Patterning Method for Ink-Jet Printing Process

Chih-Jian Lin, Chih-Hsuan Chiu, Chia-Ming Chang, Gian-Hung Liu, Yung-Kuo Ho, Jane Chang, and Kevin Cheng, OES/Industrial Technology Research Institute, Hsinchu, Taiwan, R. O. C.

Abstract

Traditional ink-jet printing algorithm for patterning fine resolution image is to split the image at fine swath length, and then to control the stepping distance along the moving direction of the substrate, commonly called interlaced printing. However, this method is not appropriate for some applications, especially for displays fabricated by ink jet printing, primarily due to the incompatibility of the nozzle arrangement with most panel resolution. Simple interlace printing method would cause offsets in between each swath. The tiny position deviation from the mismatch of nozzle pitch and the panel resolution produces fetal damage in quality, or named "mura" in display terminology. This paper proposes a novel printing algorithm and memory arbitration mechanism for patterning fine images. It combined the benefits of rotating print head rotating and interlaced printing. By bit data shifting operation, the printing process is synchronized with the triggering signal and is independent with panel resolution, which resulted in more flexible print resolution and memory usage save. The results showed that the resolution can modulate up to 1μm for JPEG, TIFF, Gerber RS274X data format, and no "mura" is observed from swath to swath for display applications.

Introduction

This paper disclosed a tunable resolution and patterning method for ink-jet fabrication for Printed Circuit Board (PCB) and display application. Ink-jet printing has the innate characteristics of saving material and directly patterning.[1,2] Kevin Cheng[3-5] shown the feasibility of ink-jet fabrication for color filter; which can simplify procedure and avoid high equipment expense. More important of the ink-jet fabrication is, the yield rate will decrease as size increases. For display application, most of pattern is regular matrix data, which only horizontal resolution (parallel to printing direction) and perpendicular resolution (vertical with printing direction) need to be considered. However, different with display, the PCB application has versatile sub patterns like circle, line, square, slant line, non-regular pattern; those of pattern are hard to keep required resolution and same line width by ink-jet printing, especially for the slant direction of printing.

This paper construct a process flow which consists of (1) image trimming, data manipulation and firing arbitration, to adapt to the fine pattern and tunable resolution requirement for PCB and related application. The image trimming first transfer standard Gerber RS274X format to raster data, then by trimming skill to modify the resolution for individual pattern. Data manipulation arranges the data library for rotation relation of head and trimmed image, to stack data into memory at optimal performance. Finally, the firing arbitration combines the drop on demand, waveform generation, and trigger command to discharge ink drop into predetermined location.

Image Trimming

An ink-jet printing system for forming circuit patterns onto the surface of a printed circuit board (PCB) needs a different input data from classic PCB processes. The standard protocol of PCB is Gerber RS274X, which is a description language, not raster data for ink-jet printing. Traditional raster data sets matrix dot overlap for horizontal and vertical direction at certain resolution, it causes the resolution loss while printing on the substrate because of the wetting behavior and specific pattern, for example, the slant line. Therefore, a correcting image process is needed to develop. There are lots of researches into the field of printing quality,[8] but non of their studies mentioned how to process said resolution problem. Different with commercial inkjet printer, the printing quality is no only for ocular vision, but is extremely precise at each dot position and its line tracking present. Chiu et al.[9] proposed a system consists four major phases to solve this problem, as shown in Fig. 1.

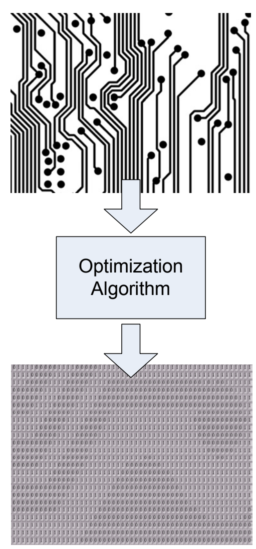

Figure 1. Gerber format to printable data format

Follow Chiu et al. procedure, in this paper, the optimum processing contains four steps. The first step is converted RS274X format into binary image array data. Converted resolution is selected in order to achieve at desired registration precision level of the PCB. The second step is to divide the binary image into small parts for image segmentation.[6] Size of the divided image is a factor influencing the success rate of image recognition. The reason is that divided size has a selective effect on segmenting image. For the discrete images, which have more than two edges broken by cut line are classified to larger images. The third step is the verification and inspection step used for separating different kind of image such as circle, horizontal line, slant line, vertical line, square, filled and blank, etc.[7] All of these verified patterns will be trimmed by respective modifying rules in the final step. After these processes, a classic description language data (Gerber RS274X) has been transferred and trimmed into raster data (TIFF / JPEG).

Data Manipulation

In order to attain the expected printing resolution, the image data needs in accordance with nozzles arrangement at different rotation angle for following firing procedure, here is referred as, data manipulation, where the rotation angle of the print head, the interlace times and the delay timing of the each nozzle are important consideration to implement as following steps:

Step1: Resolution for Head Rotation

When the rotation angle θ of print head is determined by user, the approximate resolution z can be computed from the nozzle distance D of the print head and the rotation angle θ. Figure 2 is the diagram of rotation print head. In this figure, b and a are quotients of Y/z and X/z.

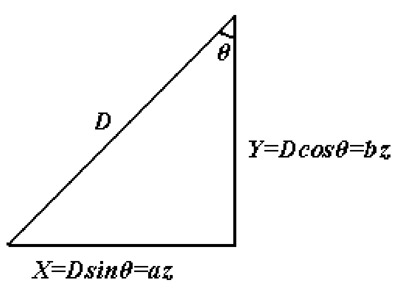

Figure 2. The diagram of rotation print head

Step2: Interlace Algorithm

The quotient b is also the interlaced times of interlaced printing method in the printing process, and the quotient **a** is the delay count of image re-arrangement step. The image re-arrangement step will be explained in the following article, and the interlaced times indicates the times of printing in the region between two adjacent nozzles. For implementing the interlaced printing method, the quotient of **Y/z** should be an integer. While checking whether the quotient **b** is a reasonable value, the tolerance of feed could be considered to make the resolution picking process easier and more creditable.

Step3: Data Splitting & Arrangement

After the steps 1-2 are carried out repeatedly, the rotation angle list can be built up to pick a rotation angle in accordance with the requirement of the application. When the rotation angle and the interlaced times are decided, the split step and the re-arrangement step will be carried out so that the image data will become a suitable form for firing by the firing module. In this step, the image data will be divided into swath data which are depend on selected nozzles of the print head. The interlaced times and the nozzle distance in vertical direction has been calculated. As an example, the interlaced times **b** and the distance of nozzles in the vertical direction **Y**, will be arranged as follows:

$$\mathbf{b = Y/PR,}$$

where PR is the pattern resolution. Since Y is the distance of nozzles in the vertical direction, it can be computed by:

$$\mathbf{Y = D\cos\theta,}$$

where D is the nozzle distance and θ is the rotation angle of the print head.

Step4: Data Stacking in Memory

After that, the image data must be re-arranged and filled up with dummy values to a parallelogram format swath-by-swath to fit the firing algorithm of the firing module. To re-arrange the image data, rows of swath data will be shifted and filled up with dummy values according to the delay count of rotated print head, named the quotient of X/PR, where X is the distance of nozzles in the horizontal direction and PR is the pattern resolution. Figures 3-4 illustrated the relationship between the original image and the modified image by the above-mentioned split step and the re-arrangement step. When the timing delay is **a**, the n^{th} row of the swath data must be shifted by (n-1)×a columns and the vacancy be filled up with dummy values. The value X is the distance of nozzles in the horizontal direction that can be computed by the following formula:

$$\mathbf{X = D\sin\theta,}$$

where D is the nozzle distance and θ is the rotation angle of the print head.

All the swath image data will be stored into memory as the firing data. The access mechanism such as the Direct Memory Access unit (DMA), can be used to transport image data to the firing module.

For each swath printing, the communication of data will limit the printing speed. We designed a cyclic data exchange method for each printing at multi-task process. In operation for each swath, a parallel data transfer task into memory **B** while printing data of memory **A**, and an overwrite task of memory **B** into memory **A** executes at the return of print head. Therefore, before execution of printing, several sets of commands were established to synchronize the master control unit and the printing system. Those commands will be transferred by the transfer device before starting of printing and before printing of each swath. And the system firmware of the printing system can be used to parse those commands to set the firing module for the printing process. Through appropriate arrangement of image data and correct printing information setting, the printing process can be executed by the firing module based on the firing algorithm.

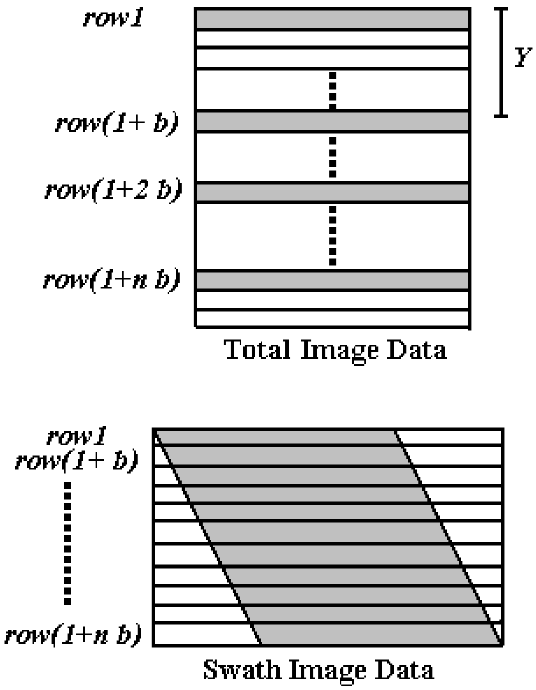

Figure 3. Denotes the total image data split by the split step

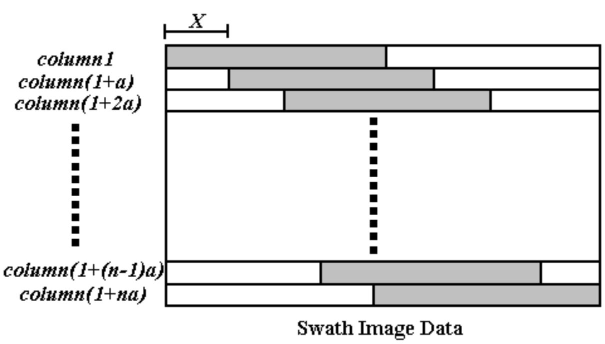

Figure 4. Denotes the swath images re-arranged by the re-arrangement step

Firing Arbitration

Generally, the print head is restricted fix pitch between nozzles and of course, limit the tunable possibility for pixel resolution. In this design, we define the Pattern resolution (PR) as the resolution of pattern, Divided Number (DN, which related to the triggering density to fire data), Delay count (DC) as the distance between nozzle to nozzle, the Runway Count (RC) as the distance that from the first nozzle to start-firing-point, the Trigger index (TI) as encoder pulse. The rules in Fig. 5 for this algorithm are:

1. PR must divide by DN with no remainder.
2. DC must divide by DN with no remainder.
3. RC must divide by DN with no remainder.
4. Quotient of DC/PR said QQ also divides by DN with no remainder.
5. Remainder of DC/PR said RR also divides by DN with no remainder.

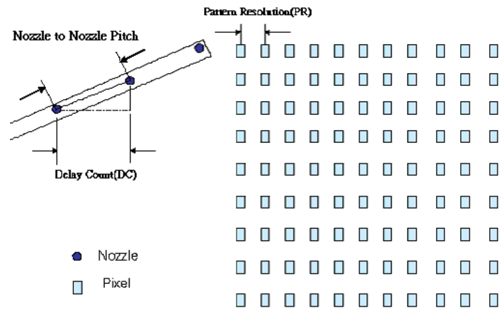

Figure 5. Printing Diagram

For each triggering loop, the algorithm logic is

Block 1

If (TI / DN is integer then)

Pixel Position (n, m) = (RC + (n-1)*DC + (m-1)* PR) / DN where n is the nozzle number and m says column of pixel.

Block 2

1. Examine if all of RC、 DC、 PR are multiple of DN
2. Wait for triggering signal to access memory data

Block 3 Access DMA Data

Firing module uses DMA method through OES DMA bus to transmit image data (see Fig. 6). DMA includes two channel signals: request and ack, one 32 bits data signal, and one common signal: done. Request signal informs DMA to read data from SRAM on AHB bus. Then DMA transmits ack and data signals to firing module simultaneously. When data transmit finish, DMA will send done signal to firing module.

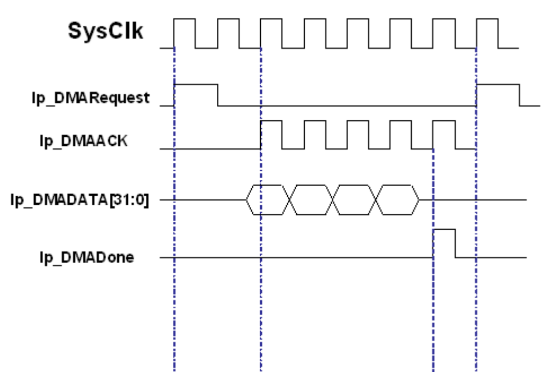

Figure 6. DMA timing trace

Block 4 Firing Synchronous

Firing module includes a top-module: E_APBMainFire, it receives some specific parameters from F/W then transmits some to F/W. E_Firing_Ctrl_top controls all sub-module such as E_Encoder_IF

、E_DMAInterface、E_BufferManager、E_Buffer、E_Firing_ Output_SE and E_Firing_Output_SX.

E_Encoder_IF generates encoder pulse; E_DMAInterface delivers image data from SRAM to E_Buffer module; E_BufferManager controls buffer data, which has been written or read.

E_Firing_Output_SE and E_Firing_Output_SX transmit image data from buffer and firing pulse to print head driver IC. Figure 7 is the block diagram of firing.

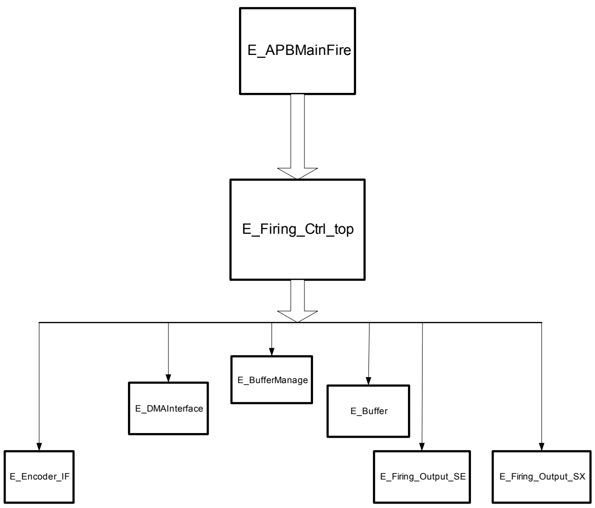

Figure 7. Firing Block Diagram

Conclusion

In this paper, we disclosed a new design of printing method which allowed for tunable resolution and arbitrary pattern capacity. This method modified traditional interlace printing method that has offsets in between each swath at different resolution. This printing method is synchronized with the triggering signal and is independent with panel resolution, which resulted in more flexible print resolution and memory usage save. Three modules are constructed in this method, the image trimming, the data manipulation, and firing arbitration. By signal simulation, we found this design and memory arbitration can tuning resolution up to 1μm with high accurate mechanical rotation as well as system clock of 50MHz, and the JPEG, TIFF, Gerber RS274X data format can be precisely transferred. It is expected no “mura” occurred for swath to swath for display applications.

References

1. Richard Bennett and Dave Albertalli, “Use of Industrial Inkjet Printing in Flat Panel Displays” International Display Manufacturing Conference (IDMC), 2005.
2. David Albertalli, “Gen 7 FPD Inkjet Equipment – Development Status”, Society for Information Display (SID), 2005.
3. Kevin Cheng et al, “A Novel Application of Ink-Jet Printing Technology on Manufacturing Color Filter for Liquid Crystal Display”, NIP 17: International Conference on Digital Printing Technologies, pp.739-743, 2001.
4. Wanda Wan-Wen Chiu, and Kevin Cheng et al, “Ink-Jet Printing Technology on Manufacturing Color Filter for Liquid Crystal Display Part I: Ink-Jet Manufacturing Processes”, NIP 19: International Conference on Digital Printing Technologies, pp.303-308, 2003.
5. Kevin Cheng, et al, “Ink-Jet Printing Technology on Manufacturing Color Filter for Liquid Crystal Display Part II: Printing Quality Improvement”, NIP 19: International Conference on Digital Printing Technologies, pp.309-313, 2003.
6. M. Moganti and F. Ercal, Segmentation of Printed Circuit Board Images into Basic Patterns, Computer Vision and Image Understanding 70, 1998, 74-86.
7. M. Moganti and F. Ercal, A subpattern level inspection system for printed circuit boards, Computer Vision and Image Understanding 70, 1998, 51-62.
8. Stephen F. Pond, Ph.D, “Inkjet Technology and Product Development Strategies”, Torrey Pines Research, 2000.
9. Chih-Hsuan Chiu, Chung-Wei Wang, Ming-Huan Yang, Chih-Jian Lin, Jane Chang, Jinn-Cherng Yang, Chun-Jung Chen, and Kevin Cheng, “Image Segmentation and Trimming for Ink-Jet Fabrication of Electronic Circuits“, accepted by First International Conference on Digital Fabrication Technologies, 2005.

Author Biographies

Chih-Jian Lin received his Master degree in Mechanical Engineering from National Taiwan University of Science and Technology in 2001. He is now a system integration engineer in the Printing Technology Division, Opto-Electronics and Systems Laboratories of Industrial Technology Research Institute at Taiwan. His work has primarily focused on the Opto-mehantronic integration and industrial ink-jet printing processes development, as color filter, Polymer Light Emitting Device (PLED), micro-lenses, organic TFT by ink-jet printing, etc. LCJ@itri.org.tw.

Kevin Cheng received his B.S. degree in Mechanical Engineering from the University of Tamkang at Taiwan in 1992 and a Ph.D in Aeronautics & Astronautics from National Cheng Kung University in 1998. He is now a system integration segment manager in the Printing Technology Division, Opto-Electronics and Systems Laboratories of Industrial Technology Research Institute at Taiwan. His work has primarily focused on the system integration and industrial ink-jet printing processes development, as color filter, Polymer Light Emitting Device (PLED), micro-lenses, organic TFT by ink-jet printing etc.