Dynamic Management for Multiple Rotation Printheads with Interlace Printing: Part II: Patterning Algorithm

Chia-Ming Chang*, Chih-Jian Lin & Kevin Cheng, Industrial Technology Research Institute, Hsinchu, Taiwan, R. O. C. ,E-Mail :cmchang@itri.org.tw

Abstract

For patterning images with particular objective pattern resolution by ink-jet printing, some system characteristics should be considered. For example, the physical layout of nozzles usually unmatched with the pitch distance in real fabrication. This article proposed a novel data formatting method based on the manipulation of original image data according to the physical layout and the driving time period of printhead. Through image slicing procedure calculated on rotational pitch, swath times, panel size etc., the original image data will be re-arranged to a format compromised with the drop on demand setting, patterning resolution for vertical and horizontal printing direction, and firing speed. By this so-called interlace-rotation algorithm in this article, the unmatched resolution between the nozzle distance and pixel pitch, it will be bring with together by the calculation of quote and reminder relationship to establish a look-up table, and no resolution loss in printing can be realized. Also, this scheme can operate bi-direction printing in simply conversion method and support user friendly as well as adaptability at plurality of printheads without any change required. This flexibility with compact memory usage will be helpful to mass production with modularized design and large size panel application. Results shown that the printing resolution can be continuous tuning from 100 dpi to 5080 dpi, in consistence and no mura was observed.

Introduction

This article describes consideration of the system architecture and its memory arbitration method for ink-jet fabrication of the Printed Circuit Board (PCB) and display. This memory arbitration method, also called as the dynamic image data management method, arranges the image data for the rotation relation of printheads [1] to forward the usage of stocking memory. Prior works by Cheng et al. [1-5] discussed the feasibility of ink-jet fabrication. It has the innate benefits of saving material, direct patterning [6][7], and decreasing the yield rate as the panel size increases.

In the ink-jet printing procedures, in order to obtain the expected printing resolution, it is required that the image data are conformable to the nozzle arrangement at different rotation angles. If the printhead is fixed and no rotation angle relative to printing direction image data are simply split based on the printing resolution and the interlace interval of the interlace printing method [8]. But for real fabrication such as display application, it needs variable pitch assignment to fit customer requirement, and generally a mismatch between the pixel pitch and nozzle pitch were occurred. It will result in resolution loss during printing and create the defect on the panel, or generally named as "mura". Most of ink-jet printing adopted rotated printheads relative to the printing direction [9], to tuning the nozzle pitch fitted with pixel pitch, and the challenge is the resolution loss and the complex of management of image data. .

This article disclosed an algorithm for ink-jet printing in a relative angle to printing direction, its image slicing, data management, and the resolution refining algorithm. Especially, the user friendly and dynamic memory management proposed by this article are helpful to mass production with modularized design and large size panel application in ink-jet fabrication.

Pattern Resolution Matching

Previous researches proposed the single-pass method [10] with the rotated printhead method to solve the above-mentioned unmatched situation. In this so-called direct-fitted printing method, as shown in Fig. 1, the printhead is rotated so that the nozzle distance in the vertical direction can fit the objective pattern resolution.

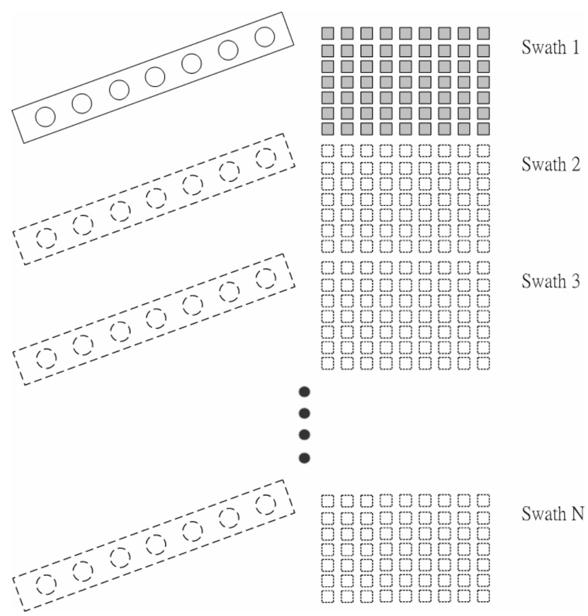

***Figure 1**. Direct Resolution Fitted Printing Method*

Fig.2 shows the geometric relationship of the rotated printhead. In this figure, d is the nozzle distance of the printhead, d_v and d_h are the components of nozzle distance d in the vertical and horizontal directions respectively, and ▯ is the rotation angle of the printhead. In the case of direct-fitted printing method, the nozzle distance in the vertical direction d_v is just equal to the pattern resolution PR. The relation of PR and d can be formulated as:

$$\theta = Inv[\sin(PR/d)] \quad (1)$$

, where Inv denotes the inverse trigonometric function.

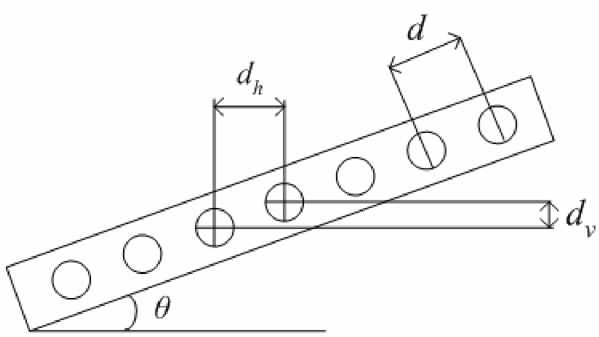

***Figure 2**. Geometric Relationship of the Printhead*

In this rotated printhead method, the physical layout of nozzles matches with the pitch distance. It is low complexity, easy to realize and can reduce visible swath marks. However, for most of piezo printhead, all the nozzles are charged driving energy at the same time. It makes the printing speed will be limited for the non-matching of printing pattern. In the other word, for high resolution printing or high speed printing, the firing signal need to be triggered at each tiny step (receive position signal and ready to fire ink) for matching each deposition position, and makes the printing speed limited. For example, in our experience, at ±1 um triggering resolution, the printing speed will be under 1 in/s, and low throughput is expected. To solve this crucial problem, a new methodology combined the rotational data management and interlace printing were proposed.

Fig. 3 shows this mis-match deposition situation. In this figure, these four nozzles are simultaneous driving nozzles, and the patterning resolution PR is just equal to the vertical nozzle distance component d_v. After n times of nozzle firings it will be observed that there is an oblique line with the slope of:

$$d_v/((d_v \times n) - d_v) \quad (2)$$

By use of the rotated printhead with interlace printing method [1], and a divided frequency technology developed by display technology center / ITRI, Taiwan [11], the difficulty in unmatched resolution between nozzle distance and pixel pitch can be solved and printing at high speed up to 20 in/s. In order to obtain better printing resolution, the group of simultaneous driving nozzles should have matching components of nozzle distance in both horizontal and vertical printing directions with the pattern resolution in this angle. Rotation angle θ of the printhead is pre-determined by computing algorithm and the objective resolution will be slightly amended to improve the accuracy of printing. Besides, the ink drops fired from simultaneous driving nozzles will exactly deposit at the precise position because the nozzles have already aligned to these position through said method, which not only promotes the utilization rate of nozzles but also accelerates the printing speed. The printing data can be substantially reduced in memory use due to it avoids of unnecessary insertion of dummy values. Fig. 4 denotes the interlace-rotation patterning and its algorithm, and the detail calculation was introduced below.

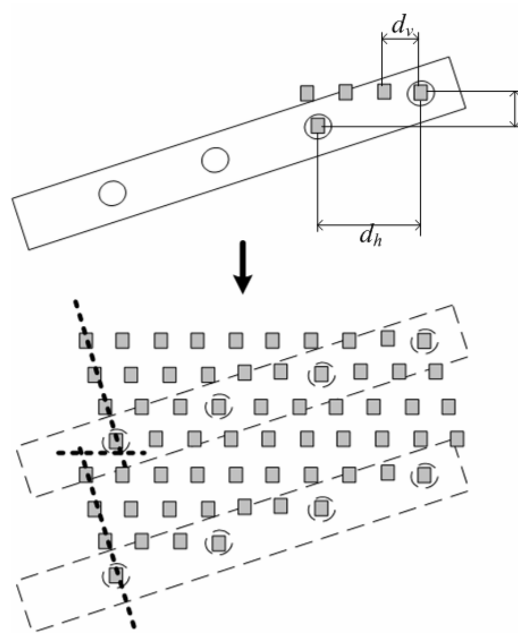

Figure 3. Meantime-Driving Nozzles and Crooked Lines

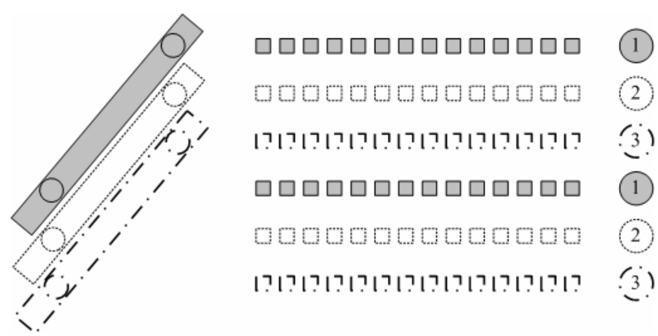

***Figure 4**. Diagram of Interlace-Rotation Algorithm*

In the above-mentioned interlace-rotation method, it operated by inspecting if the quotients of the nozzle distance divided to the pattern resolution for both horizontal and vertical directions were positive integers. The quotient of the nozzle distance and the pattern resolution in the horizontal direction Qx and that in the vertical direction Qy can be computed by the following formulas respectively. Where

$$Qx = d_h/PR \quad (3)$$

and

$$Qy = d_v/PR \quad (4)$$

were defined. In some situations, several groups of simultaneous driving nozzles in a printhead were occurred, then each simultaneous driving nozzle group should have matching components of nozzle distance in both horizontal and vertical printing directions with the pattern resolution. Furthermore, the quotients of the nozzle distance and the pattern resolution Qx and Qy must also be equivalent for every nozzle group.

This design can be easily expand to use for multi-printheads operation [12]. In the similar way, while the relative position relation of each printhead equal to the multiples of the patterning resolution, and the quotients of the nozzle distance and the pattern resolution Qx and Qy are equivalent between every nozzle group, its printing procedure control and the data management method are almost the same as that of the above-mentioned single printhead algorithm.

For further explain to detail, the above-mentioned direct resolution fitted printing method in Fig.1 is a special case of this interlace-rotation patterning method, if the quotient of the vertical component of the nozzle distance and the pattern resolution Qy is setting to equal to 1, i.e.

$$Qy = d_v/PR = d_v/d_v = 1 \quad (5)$$

Follow this procedure, once the printheads have accuracy relative position defined, the image data can be manipulated according to the rotation angle, driving time period of printheads, rotational pitch, swath times and panel size etc., to rearrange the data format to obtain the required fabrications.

Dynamic Data Management & Patterning Algorithm

Before starting the data management steps, the image data must be transferred to a bit stream from the format of Bitmap, TIFF, JPEG, Gerber or other image data formats. These image data are processed by halftone algorithm [13] to become printable bit stream data. After those binary (1 or 0) data are arranged sequentially according to the relative moving direction between the printhead and the substrate, the dynamic management can then be executed to manipulate the bit stream data.

The first step of the management process is to re-arrange the bit stream in consist with printing swaths. In other words, the printing data will be lined up one after another to be fired in each swath. By considering the information including the panel size, patterning resolution and interlace times, the bit stream can be manipulated by slicing and re-arranging the swath data. Fig. 5 shows an example of the swath data slicing in the order of swath numbers.

In Fig. 5, the printing data for each swath are split out in sequence. For example, the interlace times is three (1st interlace, black square, 2nd interlace, white square, 3rd interlace, gray square,), the interlace data length is four for each nozzle at certain interlace printing, and the total printing data length for each nozzle is equal to interlace times multiplied by interlace data length, the twelve, As the indicated in Fig.5, the first row contained the first nozzle and the second nozzle printing data, in total of twenty-four. Similarly, the computing formulas are concluded as follows:

$$L=PL/PR \quad (6)$$

$$I=L\times IT \quad (7)$$

, where L is the swath data length, PL is the panel length, PR is the patterning resolution, and IT is the interlace times. The interlace-rotation algorithm as the above formula can be modified to:

$$I=L\times Qy \quad (8)$$

, in which the starting address of the swath data in each nozzle can be computed by the following formula:

$$Adds=SN+IT\times I\times N \quad (9)$$

$$N=0, 1, 2,... ; SN=0, 1, 2,...$$

, where Adds is the starting address of each nozzle, SN is the swath number, N is the nozzle number, and IT is the interlace times.

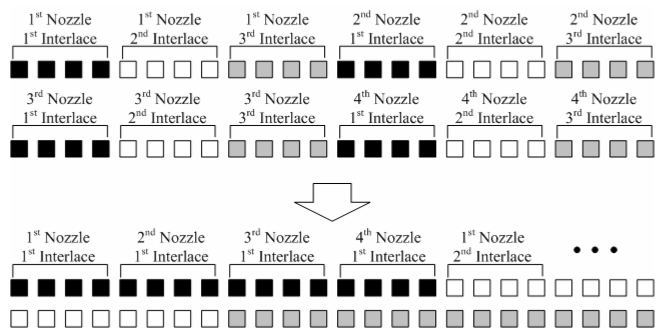

***Figure 5**. Management of interlace data slicing (1st interlace, black square, 2nd interlace, white square, 3rd interlace, gray square), where the data in same interlace were collected to a continuous data, to be printed.*

After the swath slicing step, all the data were stored in memory as shown in Fig. 6, then we abstracted the same interlace data (for example, the black color for 1st interlace) for all adopted nozzles, and collected the data into a square map.

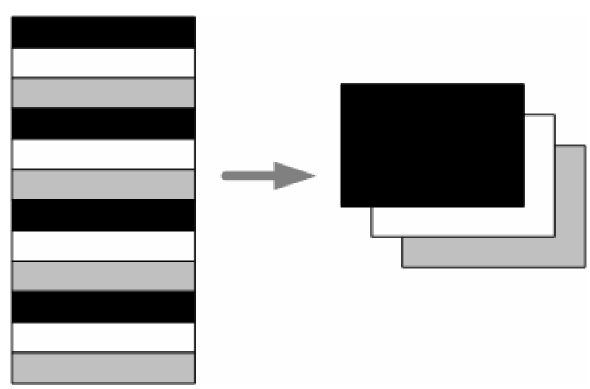

***Figure 6**. Data mapping of each interlace for all adopted nozzles.*

Fig.5 and Fig.6 described a data format for regular interlace printing, without considering the head rotation angle. If the head has tilted at an angle with the printing direction, it will make the extra data created for covering the panel range. As shown in Fig. 7, each nozzle in a rotated printhead enters the print-margin in sequence. However, limited by those nozzles were in the simultaneous driving group, the bit stream data corresponding to each nozzle must be manipulated so that dummy values will be inserted individually. This inserting process of dummy values is called the nozzle data shifting step.

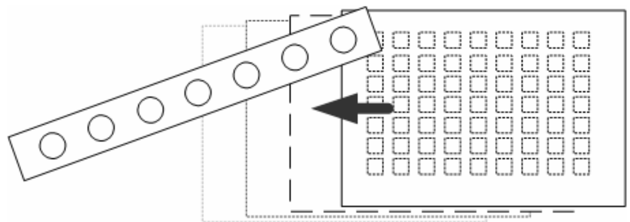

***Figure 7**. Sketch for rotation of print head and image pattern.*

When operates interlace-rotation algorithm, dummy values are inserted to the bit stream data corresponding to each nozzle according to the delay count quotient Qx, which is a function of rotation angle. Fig. 8 shows the nozzle data shifting step executed to the bit stream data process. Dynamic management procedure inserts several dummy values in between bit stream data that are relative to nozzle order. For example, the printing data of first nozzle is marked as black, dark gray for 2nd nozzle, gray for third nozzle, and white for fourth nozzle. It is noted that the dummy value inserted into the data because of the rotation angle at printhead will make the timing delay between nozzles, depends on the printing resolution needs. The computation formula for the number of dummy values is:

$$N=S\times DC \tag{10}$$

, where N is the number of dummy values, DC is the delay count, and S is the sequence entering parameter decided by the order of nozzles entering the print-margin. For this interlace-rotation algorithm, the above formula can be modified as follow:

$$N=S\times Qx \tag{11}$$

As regards the drop on demand patterning [8], it can be implemented by just turning off nozzles if it can be driven separately. But in the case of simultaneous driving nozzles, the dummy values must be inserted into the bit stream data to assure the correctness of deposition. The number of dummy values can be computed by the following formula:

$$N_d=L \tag{12}$$

, where N_d is the number of dummy values inserted for the drop on demand setting and L is the swath data length mentioned above, which is computed by the patterning resolution and the panel size. Through appropriate dynamic data management procedure including the swath slicing and the nozzle data shifting steps, the image bit stream data can be deposited by the firing module to obtain more accurate products.

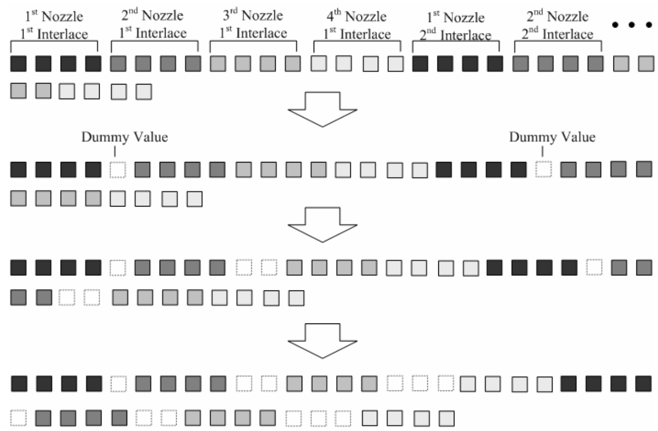

***Figure 8.** Data management for interlace-rotation printing, the data in different color were for nozzle in order, black (1st nozzle), dark gray (2nd nozzle), gray (3rd nozzle), white (4th nozzle)*

Result & Discussion

This data management shown the capability of continuous tuning of patterning resolution from 100 dpi to 5080 dpi, as in Table.1. Where, OPR is denoted the objective patterning resolution, APR is the approximate patterning resolution, θ is the rotating angle of the printhead, DC is the nozzle shift delay count, and IT is the interlace times. It was observed that when the pattern resolution is not a multiple of the resolution of the printhead, the interlace-rotation method can compensate to desired images through printhead rotation. However, some errors caused by precision of position, scale of encoders, and other physical constrains should be carefully calibrated in the future.

Table 1: Calculation results for interlace-rotation algorithm

OPR (μm)	OPR (dpi)	θ	APR (dpi)	APR (μm)	DC	IT
5.0000	5080.0	61.16	5080.0	4.9999	89	49
5.29167	4800.0	0.00	4800.0	5.2917	0	96
5.6444	4500.0	0.00	4500.0	5.6444	0	90
6.0000	4233.6	14.36	4233.3	5.9998	21	82
6.3500	4000.0	0.00	4000.0	6.3500	0	80
7.0000	3629.3	22.29	3628.6	7.0000	28	67
7.9357	3200.0	0.00	3200.0	7.9357	0	64
8.0000	3175.3	63.84	3175.0	7.9994	57	28
9.2364	2750.0	0.00	2750.0	9.2364	0	55
10.0000	2540.0	53.81	2540.0	9.9997	41	30
12.7000	2000.0	0.00	2000.0	12.7000	0	40
15.0000	1697.0	45.00	1697.1	14.9671	24	24
20.0000	1270.0	45.00	1272.8	19.956	18	18
25.4000	1000.0	0.00	1000.0	25.4000	0	20
30.0000	846.7	29.93	1200.0	29.9342	0	24
40.0000	635.0	45.00	636.4	39.9122	9	9
50.8000	500.0	0.00	500.0	50.8000	0	10
60.0000	423.3	45.00	424.1	59.8984	6	6

80.0000	317.5	38.66	320.1	79.3366	4	5
84.6667	300.0	0.00	300.0	84.6667	0	6
127.0000	200.0	0.00	200.0	127.0000	0	4
508.0000	100.0	0.00	100.0	508.0000	0	2

Conclusion

In this article, we disclosed a patterning algorithm of dynamic management for multiple rotation printheads with interlace printing. This algorithm has the adaptability to different settings of objective pattern resolutions and arbitrary input patterns, and the capability to figure out the placement of printheads by simply checking the parameters of quotients. Furthermore, the image data can be manipulated by several steps to make the printing data conformable to the architecture of the printhead placement. It combines the benefits of the interlace printing method and the printhead rotated method. By choosing the harmony system parameter, the complexity of slicing swath data in the interlace printing method will be simplified and the crooked deposition caused by the rotated printheads can also be amended.

Through development of the ink-jet depositing system, it is proved that continuous tuning of patterning resolution from 100 dpi to 5080 dpi can be done by using this memory management method. This flexibility with compact memory usage is helpful to mass production, modularized design, and large size panel application.

Reference Preparation

[1] Chih-Jian Lin, Chih-Hsuan Chiu , Chia-Ming Chang, Gian-Hung Liu, Yung-Kuo Ho, Jane Chang & Kevin Cheng, “Tunable Resolution and Patterning Method for Ink-Jet Printing Process”, Digital Fabrication 2005 - Final Program and Proceedings, pp. 89-92, 2005.

[2] 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.

[3] Wanda Wan-Wen Chiu & 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.

[4] 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.

[5] Chih-Hsuan Chiu, Chung-Wei Wang, Ming-Huan Yang, Chih-Jian Lin, Jane Chang, Jinn-Cherng Yang, Chun-Jung Chen & Kevin Cheng, “Image Segmentation and Trimming for Ink-Jet Fabrication of Electronic Circuits”, Digital Fabrication 2005 - Final Program and Proceedings, pp. 68-71, 2005.

[6] Richard Bennett and Dave Albertalli, “Use of Industrial Inkjet Printing in Flat Panel Displays” International Display Manufacturing Conference (IDMC), 2005.

[7] David Albertalli, “Gen 7 FPD Inkjet Equipment – Development Status”, Society for Information Display (SID), 2005.

[8] Anon, “Drop-On-Demand Nozzle Interlace Pattern”, IBM Technical Disclosure Bulletin, v 28, n 1, pp. 65-67, 1985.

[9] Shigeo Sakino, Kazuaki Masuda, Shinsuke Tsuruoka, Toshikazu Sakai, “Apparatus for producing color filter with alignment error detection ”, US patent, No.5984470.

[10] Lee, Dongwon; Chung, JinKoo; Rhee, JungSoo; Wang, JianPu; Hong, SangMi; Choi, BeomRak; Cha, SoonWook; Kim, NamDeog; Chung, Kyuha; Gregory, Haydn; Lyon, Peter; Creighton, Colin; Carter, Julian; Hatcher, Marie; Bassett, Owen; Richardson, Martin; Jerram, Paul, “Ink jet printed full color polymer LED displays”, Digest of Technical Papers - SID International Symposium, v 36, n 1, AAAI Mobile Robot Competition and Exhibition - Papers from the AAAI-04 Workshop, Technical Report, pp. 527-529, 2005.

[11] “Dispensing Method with Divided Synchronous Frequency Control”, Internal Report of Display Technology Center, Industrial Technology Research Insistites, Taiwan.

[12] Chia-Ming Chang, Chih-Jian Lin & Kevin Cheng, “Dynamic Management for Multiple Rotation Printheads with Interlace Printing: Part I: Flow & Memory Arbitration”, accepted by International Conference on Digital Fabrication Technologies, 2006.

[13] Li Pingshan; Allebch, Jan P., “Look-up-table based halftoning algorithm”, IEEE International Conference on Image Processing, v 2, pp. 34-38, 1998.

Author Biography

Chia-Ming Chang received the B.S. degree in Aerospace Engineering from Tamkang University, Tamsui, Taiwan in 2001 and M.S. degree in Electrical & Control Engineering from Nation Chiao Tung University, HsinChu, Taiwan in 2003. He is currently working in Display Technology Center of Industrial Technology Research Institute, Hsinchu, Taiwan, as an Associate Engineer. His work has primarily focused on the image processing and industrial ink-jet printing processes development, as color filter, Polymer Light Emitting Device (PLED), micro-lenses, organic TFT by ink-jet printing etc.