A Novel Application of Ink-Jet Printing Technology on Manufacturing Color Filter for Liquid Crystal Display

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Abstract

An ink-jet printing apparatus was setup to manufacture color filters. The apparatus includes a X-Y-θ table supporting the substrate, and a set of drop-on-demand ink-jet heads arranged on the adjustable Z-axis for coloring the filter elements. The mechanical motor drivers provide movements for the relative displacement of the substrate with respect to the ink-jet head. A processing of making color filter is discharging the predetermined color ink to the substrate, and then drying the discharged ink to form the color filter pattern. To reduce defective products caused by variance on drop position, this apparatus is additionally equipped with an optical system to detect the substrate position. This system has verified the printing behavior of three commercial print heads, HP51626A, HP51629A, and HP51645A. An image observation of the drop spot center position deviation and spot size deviation were performed. The results show the deviation range of a drop spot is within 4.01 µm, 4.10 µm, and 4.75 µm for HP51626A, HP51629A, and HP51645A, separately. This observation suggests the distance between the substrate and printhead should be closer to hide the satellite spot within main spot. In addition, the drop spot profile needs further study in order to improve its distribution characteristic on a filter element.

Introduction

Drop-on-demand printheads have emerged as one of the main printing technologies in recent years, especially for industrial applications. Two categories of ink jet printheads that are commonly used are piezoelectric ink jet (PIJ) printhead and thermal bubble ink jet (TBIJ) printhead.[1] This study focuses on the application of manufacturing color filters by a drop-on-demand TBIJ printer. Color Filter is an important constituent of liquid crystal display panel. It consists of a number of filter elements, each has R, G, B color portions and black matrix (BM) is located between the colors. The black matrix is a light-shield material used for isolating color-mixing and enhancing the contrast. FIG.1 is an exploded view of an active matrix color screen based on the liquid crystal technology.[2]

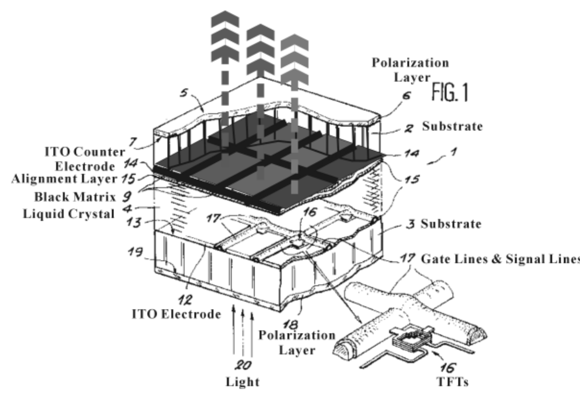

Figure 1. Exploded view of an active matrix color screen

Color filter generally requires high color purity, high transmittance, high contrast, low reflection, and high stability against heat, light, and chemical. There are four known methods to make color filter, the dyeing method, the pigment dispersion method, the electro-deposition method (ED), and the printing method. For the fore mentioned methods of fabrication, they not only require complex processing and expensive equipments but also have the limitation in the size of color filter. In addition, the yield decreases as the process and size increases. This relationship leads to very high production cost and a large amount of material waste. The characteristics of color filter are summarized in Table 1 according to these methods.[3]

Table 1. Characteristics of Color Filter

	Dyeing	Pigment	Printing	ED
Binder	A	B	C	D
Colorant	Dye	Pigment	Pigment	Pigment
Thickness (µm)	0.7-2.5	0.8-2.5	1.5-3.5	1.5-2.5
Heat Stability °C	180	220-300	250	250
Light Stability °C	<100	>500	>500	>500
Chemical Stability	Poor	Good	Good	Good
Spectrum	Best	Good	Good	Good
Surface	Good	Good	Good	Best
Resolution (µm)	7-20	10-20	70-100	10-20
Cost	Low	Middle	Middle	Middle
Processing Time	Short	Long	Long	Middle

A: Gelatin, Gasein, Acrylic, Polyimide
B : Acrylic, Polyimide, Polyvinylalcohol
C : Epoxy, Acrylic
D : Melamine, Polyester, Eopxy

To solve the problems above in manufacturing color filter, an ink-jet printing color filter system is developed.[4,5] The manufacturing processes include steps of ejecting ink of predetermined colors in a plurality of filter elements concavities, which are formed in a predetermined pattern on a template to build a color pattern layer. This technology has the potential to replace traditional methods for making color filters. However, to eliminate color mixing between adjacent color elements, the ink drops must be exactly discharged into the center of the filter elements, it leads to the requirement of a high-accuracy position control system to align the position shift between filter elements and printing nozzles. Conventionally, the ink-jet head is positioned with respect to the color filter substrate by using an alignment mark as reference, which is fabricated at the same time the black matrix (BM) is formed. The head is positioned with respect to the alignment mark. However, the BM may deviate during the manufacturing process and result in offset with respect to the head position. Besides the position error, the manufacturing process needs a lot of time in calibrating relative positions of these three printing heads (Red, Green & Blue), and the ink drops discharged on the substrate may not spread ideally on the entire surface of the filter elements. The former problem results in low production rate, and the latter results in a defective color filter with white omission. White omission is a serious defect for color filter, and causes deterioration in image quality. Therefore, the ink-jet technology must improve printing quality when applied in color filter manufacturing process.

Experimental Apparatus

In view of what is described above, this study has established an apparatus to solve these problems. First, the coloring processes are performed individually for each color, thus it reduces the calibration time of position between different color heads. Second, to compensate the position offset caused by the black matrix; this system will equip with a high-speed linear CCD to track the black matrix position, and it will real-time modulate the table motion to position the printing nozzles exactly above the centers of the filter elements. In the printing process, ink-jet heads scan relative to the substrate while coloring a number of filter elements. High precise pattern formation is achieved because the position of ink-drops is measured in advance by optical system to align the substrate with respect to the ink-jet heads. Thus, the position shift of ink-drop positions can be calibrated. Figure 2 shows a schematic view of the color filter producing apparatus.

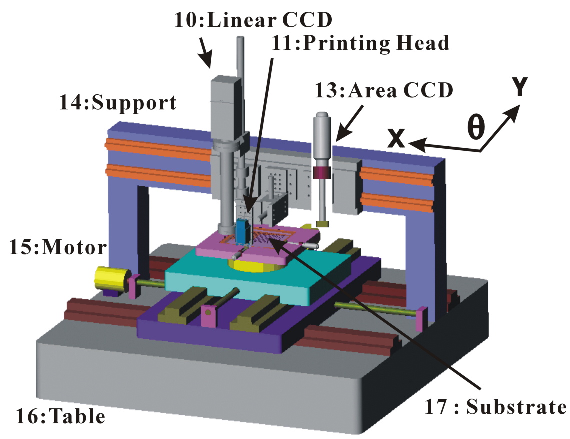

Figure 2. Apparatus Schematic

The system is based on a three-axis X-Y-θ table 16, the linear CCD 10, a set of printing head 11, and an area CCD 13 are fixed on the mechanical support 14. The set of the print heads 11 includes red, green, and blue print heads above the substrate 17. The motors 15 (one for each axis) connect to a moving stage for driving the substrate 17 in the X-Y-θ directions. In Fig. 2, the X direction is defined as the direction parallel to the support 14, the Y direction as the one vertical to the support 14. Each X or Y axis equips a 5-phase stepping motor with micro-step resolution of 0.5 µm, and maximum moving speed of 5 in/s. A rotary stage (X-Y plane) is positioned to rotate the substrate 17 in θ direction, and the rotating range is within ±3° with step resolution of 0.0025°. Moreover, the area CCD 13 reads the alignment mark positions to align the position offset when loading substrate, and these marks are formed on the substrate in advance. The linear CCD 10 is designed to compensate the track offset caused by the black matrix manufacturing process. The CCD reads the black matrix tracks and corrects the offset by moving Y stage in real-time. All the parts 10,11,12,and 13 hung on the support 14 are adjustable. This apparatus is supported on a granite base (AA Grade, 900*600*125mm) with four vibration isolators to absorb the vibration. A PC-based controller (not show in Fig.2) is used for controlling overall operation of the manufacturing process.

Droplet Observation and Image Processing

The deviation of droplet in discharged position and droplet size are the key factors in producing color filter with the ink-jet method. The manufacturing process needs to correct this deviation. In this study, three commercial TBIJ printheads were tested in this apparatus. They are HP51626A, HP51629A, and HP51645A, separately. Table 2 lists the detailed characteristics of these print heads.

Table 2. Detail Characteristics for HP Printing Heads.

	HP51626A	HP51629A	HP51645A
Color	Black	Black	Black
Nozzle No.	48	50	300
Capacity (cc)	40 ml	40 ml	42 ml
Resolution	300 DPI	300 DPI	600 DPI
Firing Rate	5 KHz	8KHz	12KHz

The optical system for the observation of the droplet consists of a PC-based controller with an image grabber card (National Instruments PCI-1411), and a motion control card (National Instruments PCI-7344, 4-axis) used for moving X-Y-θ stage. The optical system includes a light source beneath the substrate, a microscope with 56X magnification, and a charge-couple device (CCD) camera (Sony SSC-C370, 768*494 pixels, 470 horizontal scan lines, NTSC & RS-170 Video Output). These components were mounted in above-mentioned color filter manufacturing apparatus. The sampling rate of the image grabber card is up to 30 color frames per second (60 frames/s for black/white). Ink-jet heads scan relative to a substrate that was driven by X-Y-θ axis motors. The optical scale resolution is 0.5 µm for X-Y axis, and 0.002 degree for θ axis. In operation, the substrate will stop moving at each position to be discharged ink, a pulse signal trigger printing to discharge ink to the substrate, and then the camera captures image followed after a delay time. The working substrate is Epson S041063 transparency instead of glass substrate, for these commercial inks will smear on glass substrate. The firing distance between substrate and print head is adjusted at 1 mm. Conceptually, shorter distance will ensure the satellite drop land within an acceptable range, and the deviation of discharged at position is decreased. However, a distance that is too close may lead to scratch on the substrate, because the substrate surface is not perfectly flatness. This distance is determined based on experimental adjustment. Table 3 lists the operation condition for different printing heads, where the voltage is the driving power requirement; the firing pulse width is the time to heat the nozzle heater, the distance indicates the interval between adjacent drops, and the point number is the recorded discharged drops.

Table 3. Operation Condition for HP Printhead Serials

Head	Voltage (V)	Firing Pulse With	Distance	Points No.
HP 51626A	18V	2.5 µs	338µ m	24
HP 51629A	17.5V	3.4 µs	169µ m	24
HP 51645A	11.2V	2.5 µs	169µ m	24*3

Acquiring an image of quality depends on the type of analysis and processing steps. Five factors contribute to overall image quality: resolution, contrast, depth of field, perspective, and distortion.[6] In this study, the captured image was processed and analyzed in the steps below, as shown in Fig. 3.

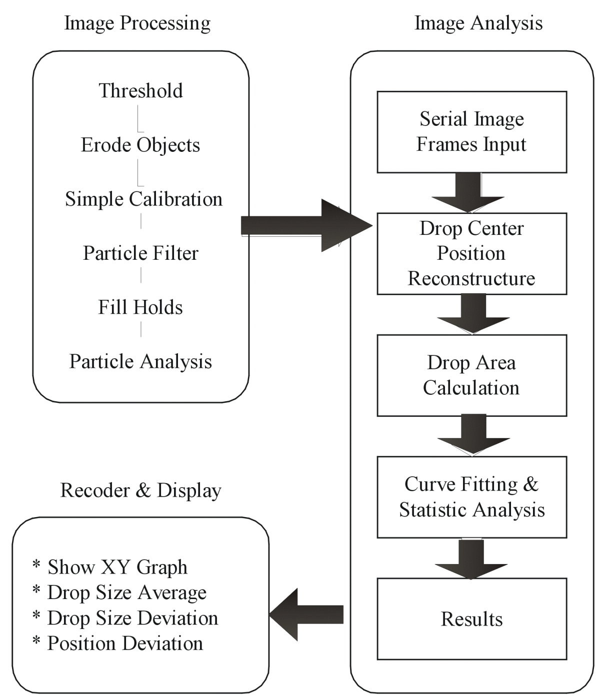

Figure 3. Image Processing and Analysis Steps

The first is the threshold step to isolate objects of interest in an image; it enables you to select ranges of pixel values to separate the objects under consideration from the background. The second step is to erode object. Erosion eliminates pixels isolated in the background and erodes the counter of particles according to the template defined by the structuring element. The structure element is a matrix data controls the effects of erosion. In this study, a 3*3 matrix with all element values equal one is adopted. The third step is a simple calibration, it transfer pixel coordinate to a real-world coordinate through scaling in the X and Y directions. The fourth particle filter step keeps or removes particles in an image according to their morphological measurements. It depends on the setting value to isolate the main drops and satellite drops in the image. The fifth step is the fill hole step; it fills the holes that are found in a particle. If the holes were in contact with the image border, they are never filled because it is impossible to determine whether these holes are part of a particle. Through these steps 1-5, the droplet in an image can be enhanced, and the center of a droplet and the size of droplet can be analyzed. Refer to the detailed flow chart in Fig. 3.

Results and Discussion

Figure 4A-C presents the discharged drop spot images for HP51626A, HP 51629A, and HP 51645A Heads. In Fig. 4A and Fig.4B, only one nozzle discharges ink droplet onto this substrate while three adjacent nozzles simultaneously fire for HP51645A in Fig. 4C. The substrate is moving at X-direction in step of 169 µm (for HP51629A and HP51645A) or 338 µm (HP51626A). This step distance is chosen for avoiding droplet overlap. In Fig.4A-4C, it is clear that a satellite drop comes with main drop. It often travels more slowly and along slightly different angular trajectories than does the main drop. It randomly distributes on a continuous droplet track. This behavior causes serious problem such as color mixing and reduce the yield rate. It is found that the bigger the firing distance is, more time is allowed for the satellite's landing point to migrate out from the diameter of the main drop spot. A simple and straightforward solution is to adjust the distance between the print head and the substrate closer so the satellite drop spot can hide within that of the main.

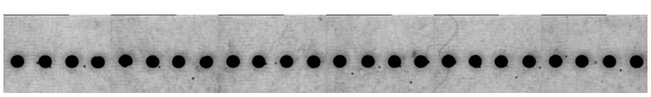

Figure 4A. Discharging Drop Spot Image for HP51626A Printing Head (Single Nozzle).

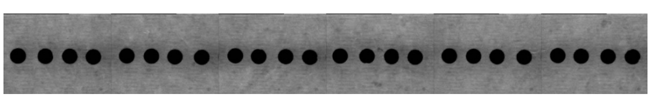

Figure 4B. Discharging Drop Spot Image for HP51629A Printing Head (Single Nozzle).

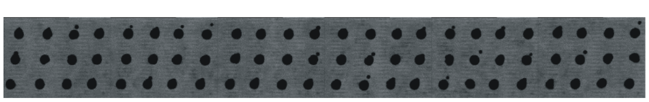

Figure 4C. Discharging Drop Spot Image for HP51626A Printing Head (Three Nozzles).

Table 4 presents the analysis of drop spot center position and size. For HP51626A print head, the deviation of center position for the drop spot is 2.37 µm, the average diameter of the drop spot is 159.82 µm, and the maximum deviation of the diameter to the average value is about 3.28 µm. In the other word, the deviation range of a drop spot will be within 4.01 µm (2.37 + 3.28 / 2 µm). The analysis for HP51629A and HP51645A are also listed in Table 4. and the deviation range are 4.10 µm. (2.79+2.61/2 µm) and 4.75 µm. (2.73 + 4.03/2 µm), respectively, where the N1, N2, and N3 indicate the different nozzle. For a standard color filter of TFT-LCD with pixel resolution of 1024*768, the dimension of a filter element (R, G, B color in a cell) is about 264 µm.*264 µm.. Each color has a approximate dimension of 264 µm*80 (depend on black matrix width) µ m. Therefore, the HP51626A and HP51629A can't satisfy with this requirement for their larger drop spot diameter. In fact, the drop size depends on the ink constituents and the firing pulse width control, but the modulation range is narrow.[1] The application of HP51626A and HP51629A is limited in manufacturing low resolution of color filter. In this analysis, it goes without saying that the HP51645A is an appropriate choice in making stand resolution of color filter.

Table 4. Deviations of Drop Spot Center and Size.

Head	Deviation of Center Position (µm)	Average Diameter (µm)	Maximum Deviation of Diameter (µm)
HP 51626A	2.37	159.82	3.28
HP 51629A	2.79	100.63	2.61
HP 51645A	N1: 2.25 N2: 2.73 N3: 2.10	N1: 66.03 N2: 64.42 N3: 64.79	4.03

Conclusion

In this study, an ink-jet printing apparatus was setup to manufacture color filters. The apparatus includes a X-Y-θ table supporting the substrate, and a set of drop-on-demand ink-jet heads arranged on the adjustable Z-axis for coloring the filter elements. The mechanical motor drivers provide movements for the relative displacement of the substrate with respect to the ink-jet head. Three commercial print heads of HP51626A, HP51629A, and HP51645A are installed in this system to observe the drop spot center position deviation and spot size deviation. The results show he deviation range of a drop spot is within 6.37 µm, 4.10 µm, and 5.4 µm for HP51626A, HP51629A, and HP51645A, separately. This observation suggests the distance between the substrate and printhead should be closer to hide the satellite spot within main spot. Besides the position deviation, the experimental observation also finds the ink drops discharged on the substrate may not spread ideally on the entire surface of the filter elements. The maximum variation in drop spot diameter is up to 8 % (for HP51645A). It will result in a defective color filter with white omission. White omission is a serious defect for color filter, and causes deterioration in image quality. Therefore, the drop spot profile needs more extensive study in order find ways to improve its distribution characteristic on a filter element.

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Biography

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 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 control system integration and developing the manufacture process of color filter by ink-jet method.