A Novel Method for Evaluating Ink-Jet Print Head Directionality

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Abstract

Directionality of droplet ejection is an important character for the ink-jet printing process in many of the industrial applications. The conventional strobe system can only be used for roughly estimating the average directionality of a group of consecutive droplets. Other apparatuses available in the market are both costly and time-consuming for multi-nozzle measurement. This study reveals a fast and economic method for measuring the directionality of a multi-nozzle print head based on every single droplet behavior. The apparatus includes an X-Y table for supporting the printed media, a drop on demand print head for ejecting droplets, and a set of optical system for capturing dot images of droplets on printed media. Software programming based on the statistic and optimization theory is also developed for calculating the ejection directionality in this study, which includes two kinds of measurement method. One is the deflection of droplets ejected from every single nozzle. The other is the deviation of the average droplet position from its ideal position. Consequently, this new measurement technique is a powerful tool for developing highly accuracy and quality of inkjet print head.

Introduction

The ideal droplet position on print media is theoretically underneath its nozzle. However, the deflection of droplet ejection is attributed to many factors such as print head architecture, printing frequency, driving signal waveform and the ink properties, etc.[1,2] This deflection is very critical not only for operating commercial ink-jet print heads but also for using ink-jet printing technology in industrial applications, especially for the ink-jet color filter and PLED (Polymer Light Emitting Device).[3] Therefore, how to estimate ejection performance is a very important issue. The conventional optical strobe observing system,[4] can only estimate the ejection direction of a group of consecutive droplets ejected from the same nozzle roughly. However, it is unable to describe a single droplet behavior of ejection. Other apparatuses using laser methods are both costly and time-consuming for multi-nozzle measurement. The above methods can still only evaluate the ejection performance in two-dimensional plane rather than in the practical three-dimensional physical space. Besides, the operating condition of print heads in these apparatuses is not completely the same as that of print heads in actually printing process.

The aim of this study is to evaluate the ejection performance of every droplet in the real physical space. Subsequently, deflection of droplets ejected from every nozzle and deviation on the average of droplet position from their ideal position can be estimated. Consequently, the printing quality of whole active nozzles can be evaluated under the practically operating condition of print head in printing process.

Evaluation of Ejection Performance

In the study, there are two methods used to evaluate droplet ejection performance by detecting dots locations upon the print media.

The Directionality of Single Nozzle

There are two important perspectives to clarify the directionality of droplets ejected from single nozzle. One is the variance of dots positions on print media, and the other is the deviation between theoretical and practical dot position on print media. Figure 1 shows one-dimensional model to illustrate following definition. The variation σ of dots locations on print media was given by[5]

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - u)^2}{n}} \tag{1}$$

where x_i denotes the ith dot position on the media, n is the count of dots, u is the average position of all dots position. Next, the deviation d between theoretical and practical dot position on the media is defined as following:

$$d = |I - u| \tag{2}$$

where I is the theoretical position of dot on the media, and d is the distance between u and I.

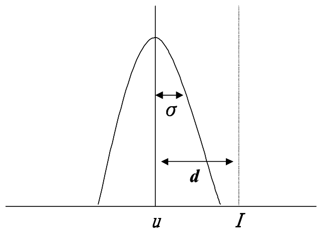

Figure 1. Illustration of the directionality of single nozzle

Theoretically, every droplet is vertically ejected from its nozzle. Thus, the theoretical dot position on print media is the projection of its nozzle position. Therefore, the most straightforward method to estimate this deviation is to compare the dot position with its projective nozzle position. However, the nozzle plate of print heads may be somewhat curved, and improper installation of a print head may cause its nozzle plate and the media surface unparallel. Doubtless, using this method to obtain the deviation between dot position and its projective nozzle position surely contain some estimation error. Thus, we develop an algorithm based on the optimization theory to correct this error and obtain the more precise theoretical dot position.

The Printing Quality of Whole Nozzles

It is even more important to evaluate the printing quality of whole active nozzles than estimate above deviation of single nozzle. As shown in Fig. 2, the dot ejected from the 5^{th} nozzle is worse than other dots ejected from their corresponding nozzles.

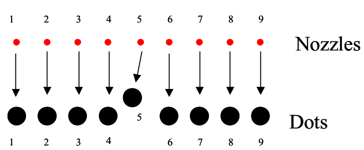

Figure 2. Illustration of the printing quality of whole active nozzles.

Moreover, when a print head is improperly installed, it is likely to lead to the change of droplet direction, because its nozzle plate and the media surface are not parallel. Inappropriate installation may result in some rotation and movement between theoretical and practical dots locations. Figure 3 shows that dots are theoretically supposed to be ejected from their nozzles to their corresponding position D_1, but practically ejected in the position D_2, because of somewhat unsuitable installation. Therefore, it may take a serious miscalculation of evaluating the printing quality of whole active nozzles by simply comparing these dot positions with their corresponding projective nozzle positions. However, in the printing process, the displacement between D_1 and D_2 is acceptable, because the traveling stage can be used to compensate it. Thus, we devised an optimization algorithm to avoid this miscalculation and successfully evaluate the printing quality of whole active nozzles. The whole evaluation process will be explained in detail on next section.

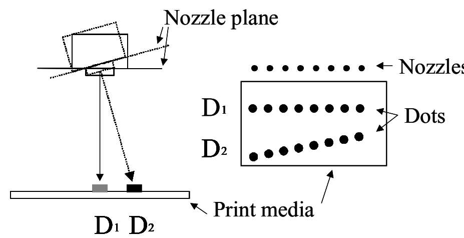

Figure 3. The influence of improper installation print head

Experimental Apparatus

This study has established an apparatus and software to evaluate the directionality of droplets ejected from every single nozzle and the printing quality of whole nozzles. Figure 4 shows a schematic view of this apparatus. The system includes a drop-on-demand print head 1, a hollow X-Y table 3 for supporting print media 2 used to receive droplets ejected from print head 1, a set of optical system 5 for capturing nozzle images and dot images, a laser displacement sensor 4 for detecting the distance between nozzle plate of print head 1 and the surface of print media 2, a X-Y table 6 driving the optical system 5 and laser displacement sensor 4. A PC-based controller (not shown in Fig. 4) is used for controlling the overall operation of inspection process and evaluating the ejection performance of print head.

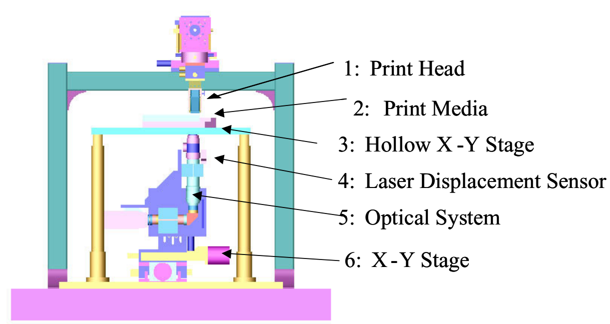

Figure 4. Schematic apparatus

Measurement of Ejection Performance

Figure 5 shows a practical printing pattern produced by above apparatus. Each column dot is ejected from the same nozzle at different moments, and each row dot is ejected from different nozzles. However, to increase the resolution of the optical system, a high magnification lens is used for improving image quality. As the field of view (F.O.V) of this lens only contains part nozzles or dots, the stage 6 is driven to different places to enable optical system to capture other nozzles or dots images, shown in Fig. 7(a). Next, these images can be merged into a complete nozzles or dots image, shown in Fig. 7(b) and Fig. 8, by using image–processing skill. The detail steps of measurement follow the flowchart shown in Fig. 6.

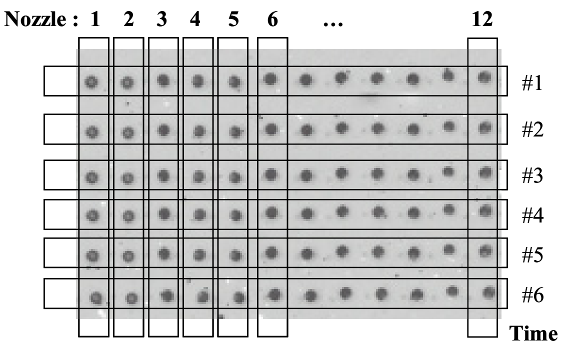

Figure 5. Practical printing pattern

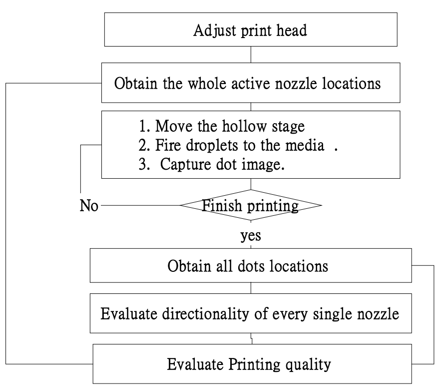

Figure 6. Measurement follow chart.

The first step is to adjust the distance and angle between nozzle plate of the print head 1 and the surface of print media 2 by using laser displacement sensor 4. The second step is to obtain the locations of all active nozzles and translate into the nozzle coordinate setting the first active nozzle position as origin. Subsequently, there are two methods to acquire these nozzles positions. One of these methods is to adopt the design specification of nozzles. The other is to merge individual nozzle images into a complete image and then acquire nozzle locations by using several image-processing skills such as image enhance, background elimination, particle analysis, etc.

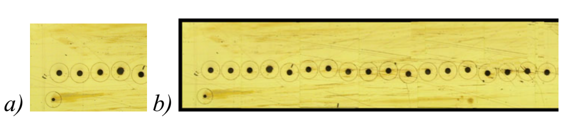

Figure 7 (a) A captured nozzle image (b) A complete nozzle image.

The third step is to produce printing pattern shown in Fig 5. First, the hollow stage 3 is driven to its indicative position. Then, droplets are ejected from active nozzles to print media 2. Subsequently, the optical system is triggered to capture dots image. To confirm the reliability of following measurement, this step keeps running until finishing entire printing pattern. The forth step is to obtain dots locations and establish the dot coordinate. However, this step is similar to step 2, because the mergence technology and image-processing skills are much alike. Figure 8 shows a complete dot image. Figure 9 and 10 respectively show different results of distinct complete images by using image-processing skills to calculate the center of every dot. Moreover, Figure 11 is a distribution chart of dots locations on the dot coordinate by recording the calculated result of each complete image. Every group of this chart represents the distribution of dots ejected from the same nozzle. Certainly, there are some variations among every dot position of the same group, because each ejection course does not keep the identical path.

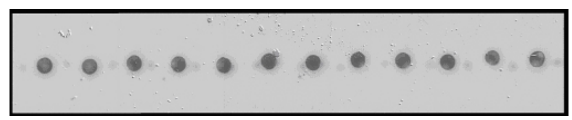

Figure 8. A complete dot Image

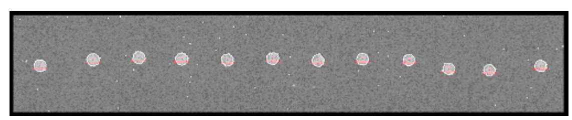

Figure 9. The result of dot image1

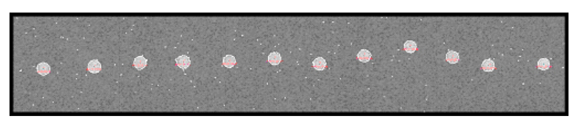

Figure 10. The result of dot Image2

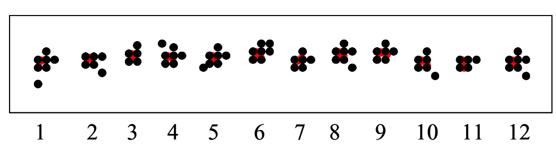

Figure 11. Dots distribution chart

The fifth step is to estimate the directionality of dots ejected from every single nozzle. Each average location and variance of dots in the same group is respectively given by equation 4 and 5,

$$(\bar{x}_j, \bar{y}_j) = \frac{1}{N_j}\sum_{i=1}^{N_j}(x_{ji}, y_{ji}) \tag{4}$$

$$\sigma_j = \sqrt{\sum_i \frac{(x_{ji}-\bar{x}_j)^2 + (y_{ji}-\bar{y}_j)^2}{N_j}} \tag{5}$$

where $(\bar{x}_j, \bar{y}_j)$ is the average dot location of the *j*th nozzle, (x_{ji}, y_{ji}) denotes the *i*th position dot in the *j*th group, N_j is the count of dots in *j*th group, and σ_j is the directionality of dots ejected form the *j*th nozzle. The final step is to evaluate the printing quality of whole nozzles. It is an absolute comparison perspective that evaluating the printing quality by comparing dots positions with their projective nozzles positions. However, it may lead to the measurement error due to improper installation and the curved nozzle plate of print head. Therefore, we put a perspective on the relative comparison by using the optimization algorithm to obtain the most possible location of the nozzle coordinate obtained by step 2, as shown in Fig. 12.

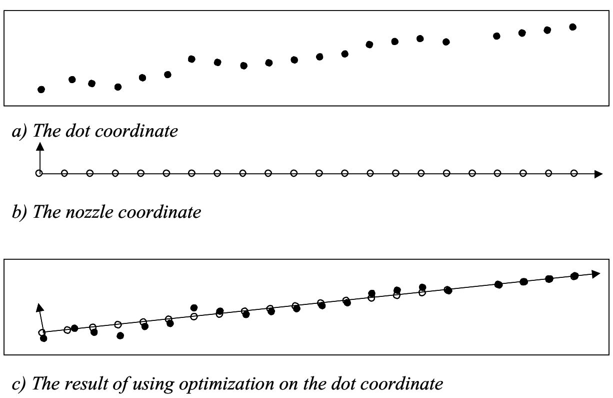

Figure 12. Illustration of the perspective on relative comparison

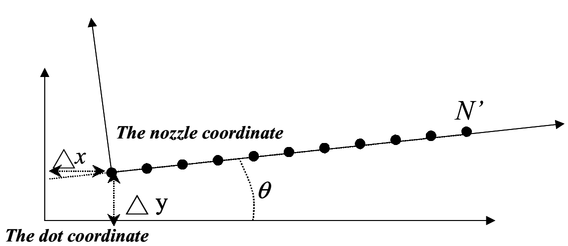

Figure 13. The expression of nozzle coordinates

Figure 13 shows the location of the nozzle coordinate *N'* on the dot coordinate. Therefore, the *i*th nozzle position $N_i(x, y)$ on the dot coordinate can be defined as:

$$N_i(x) = (x_i\cos\theta + y_i\sin\theta + \Delta X)$$
$$N_i(y) = (-x_i\sin\theta + y_i\cos\theta + \Delta Y) \tag{6}$$

where (x_i, y_i) is the *i*th nozzle position on the nozzle coordinate, θ is the angle between the nozzle coordinate and the dot coordinate, and $(\Delta X, \Delta Y)$ is the distance between the origin position of the nozzle coordinate *N*' and that of the dot coordinate. Next, the cost function *C* is defined as:

$$C = \sum_{i=1}^{M}\sqrt{\left(N_i(x)-\bar{x}_i\right)^2 + \left(N_i(y)-\bar{y}_i\right)^2} \tag{7}$$

where $(\bar{x}_i, \bar{y}_i)$ is the average position of dots ejected from the *i*th nozzle, *M* is the count of active nozzles, and $N_i(x, y)$ is the *i*th nozzle position on the dot coordinate. Moreover, there are three partial equations involving $\Delta X, \Delta Y$, and θ respectively to minimize the cost function *C*. These equations are defined as follows:

$$\begin{aligned} \Delta X_{new} &= \Delta X - k_{\Delta x}\frac{\partial C}{\partial \Delta X} \\ \Delta Y_{new} &= \Delta Y - k_{\Delta Y}\frac{\partial C}{\partial \Delta Y} \\ \theta_{new} &= \theta - k_{\theta}\frac{\partial C}{\partial \theta} \end{aligned} \tag{8}$$

where $\Delta X_{new}, \Delta Y_{new}$, and θ_{new} are new constants of cost function *C*. $k_{\Delta X}$, $k_{\Delta Y}$, and k_{θ} are descent weights of these partial equations. Next, these initial values $(\Delta X, \Delta Y, \theta)$ are selected as $(\bar{x}_1, \bar{y}_1, 0)$, the average position of dots ejected from the first nozzle. Subsequently, iterating via Eq.(8) adjusts these constants $(\Delta X, \Delta Y, \theta)$ to minimize the cost function *C*. Consequently there is a set of constants that make the cost function *C* at a minimization. Thus, every theoretical nozzle position on the dot coordinate can be obtained by putting this set into equation 6. Each nozzle deviation of the average droplet position from their ideal position can be obtained by comparing each theoretical nozzle position with its corresponding average dot position. Finally, we can evaluate the printing quality q_T of whole nozzles by using the following equation,

$$q_T = \frac{\sum_{j=1}^{M}\sqrt{(N_j(x)-\bar{x}_j)^2 + (N_j(y)-\bar{y}_j)^2}}{M} \tag{9}$$

where *M* is the count of active nozzles.

Results and Discussion

In this study, measurement methods described above and the apparatus are elaborately used to obtain the useful information about ejection performance of print head. Figure 14 shows the average dot position and its ideal position of entire active nozzles. Figure 15 shows the deflection of droplets ejected from each nozzle of print heads designed by OES/ITRI. Moreover, Figure 16 shows each nozzle deviation of the average droplet position from their ideal position and the print quality of whole nozzles. Therefore, we can learn the effects caused by changing different operating conditions, solution properties, and print head architecture, thereby developing high accuracy inkjet print heads.

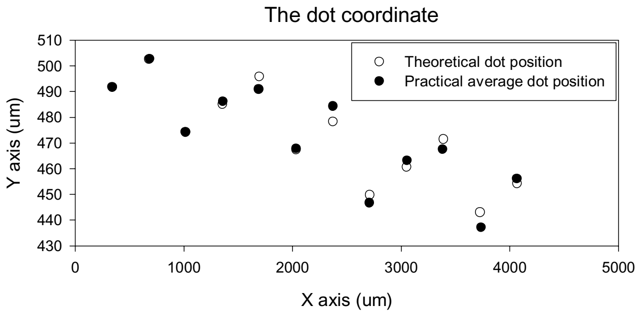

Figure 14. The average droplet position and its ideal position of whole active nozzle

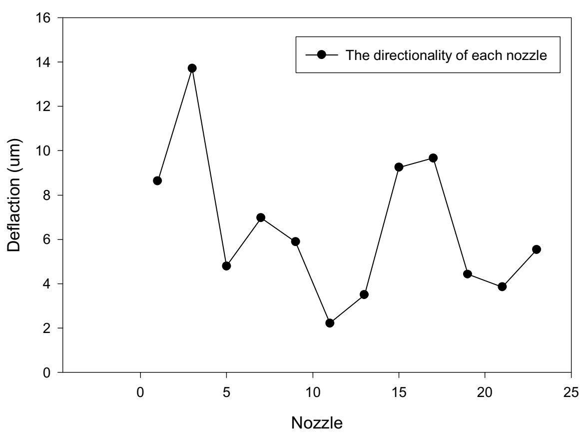

Figure 15. The directionality of droplets ejected from each nozzle.

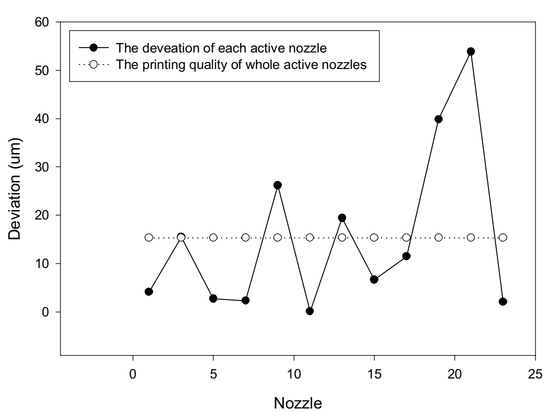

Figure 16. Each nozzle deviation of the average droplet position from its ideal position.

Conclusion

In this study, a measurement apparatus was setup to evaluate the directionality of droplets ejected from every single nozzle and the printing quality of whole active nozzles with some statistical methods and optimization algorithm. However, more study is necessary to keep improving the reliability of apparatus when operating the print head at high frequency of droplet firing.

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Biographies

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