An Impact Position Control of the Ink Droplet of Inkjet Printer

Youngwan Cho

Dept. of Computer Engineering, Seokyeong University, Seoul, Korea
(Tel: 82-2-940-7485, E-mail: ywcho@skuniv.ac.kr)

Abstract: In this paper, a position control scheme of the ink droplet is presented for the high image quality and print speed inkjet printer. The proposed scheme estimates the impact position and compensates it by control of the fire strobe time based on the dynamic equations describing the moving trajectory of the ink droplet. Compared to the conventional fire strobe control which is based on the simple synchronization the fire strobe with the position signal of the inkjet nozzle, the proposed control scheme provides more accurate impact position control during the carrier is moving with accelerated or decelerated speed as well as constant speed. The availability of printing during the acceleration and deceleration states of the carrier moving enables the print speed up and the frame size down which means the cost down.

Keywords: Ink jet printer, Impact position control, Droplet placement, Fire strobe time control

1. INTRODUCTION

The inkjet print forms an image on media by injecting ink droplet from the nozzle equipped on the carrier moving on the shaft. The conventional injection is fired by the signal that is synchronized with the encoder pulse generated from the carrier moving. This strobe scheme provides affordable image quality when the carrier moves with constant velocity. But, the carrier speed deviated from the desired constant velocity deteriorates the image quality. Moreover, when the carrier is in the acceleration or deceleration states, the image formed by conventional injection scheme is not usable because the impact position is deviated far from the desired position.

On the other hand, the printer market has been demanding higher image quality and faster print speed. The demand on image quality and print speed drives the inkjet printer to have more accurate impact position control scheme and printing ability during the carrier acceleration and deceleration states. [1][2] Thus, the impact position errors caused by the carrier speed fluctuation during the steady state moving and the speed gap between the acceleration/deceleration states and the steady state are required to be compensated by appropriate strobe time control scheme. In this paper, the impact position is controlled by fire strobe time delay that is calculated using the estimated carrier speed at the time of injection instant and the dynamic equations describing the trajectory of the injected droplet.

The dynamic equations of the injected ink droplet are derived under the assumption that the droplet is a lumped body which provides a sufficient model for the trajectory estimation of the droplet since we are not considering the interior variations of the droplet.[3][4] The flight distance of the ink droplet from injection to impact on media is determined by the parameters such as carrier velocity, distance from the nozzle plane to the media plane, injection speed, and droplet size. The mechanical parameters are fixed except the carrier velocity. Thus we can predict the impact position error by estimating the carrier velocity at the injection time and calculate the delay time to fire the injection strobe based on the predicted position error. The carrier speed at the time of injection is estimated from the previous speed data through the 2nd order estimation. The simulation and experimental results are presented to show the validity and effectiveness of the proposed control scheme.

2. TRAJECTORY ANALYSIS OF THE INJECTED INK DROPLET

The image on the media is formed by the injected ink droplets after flying through air band between the carrier and the media as shown in fig.1. The image quality is determined by the impact position of the injected droplet on the media that is affected by several mechanical and physical factors such as carrier velocity, head gap distance, injected droplet speed and droplet size. The accurate positioning of the injected droplet on the media is one of the important issues to forming high quality of image in the ink jet printer. A further understanding the trajectory of a droplet flying through air under gravity is required to control the impact position of the injected droplet.

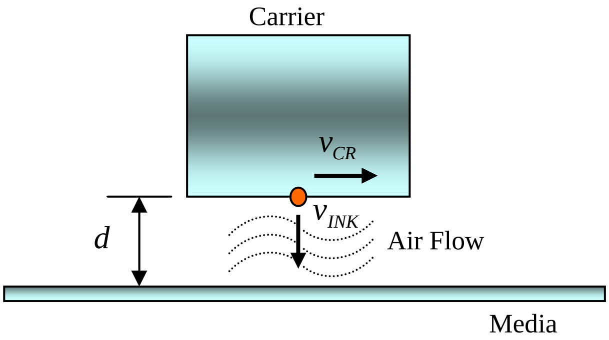


Fig. 1 The carrier, ink droplet, and media

In this paper, a simple model based on the Stokes flow over a sphere is used to estimate the droplet trajectory.[3] The droplet trajectory can be estimated by solving a set of ordinary differential equations from the force balance, in both horizontal and vertical direction, of a single droplet flying through air. In this estimation, we assume that the flow is a Stokes flow [4], and the droplet remains as a sphere rigid body through the flight. The dynamics inside the droplet is not considered and disturbance from neighboring droplets are considered negligible.

Figure 2 shows the forces acting on the droplet in the vertical direction (a), and horizontal direction (b). Two major forces, drag and gravity forces are in the opposite direction. The net force acting on the droplet induces the droplet's acceleration. The dynamic equation in the vertical direction is

$$m\dot{U}_V = -6\pi\mu R U_V + mg\,,\quad U_V(0) = v_{inject} \tag{1}$$

where, m is the mass, μ is the viscosity of air, R is the radius of the droplet, U_V is the vertical velocity of the droplet, and $U_V(0)$ is the initial injection speed, respectively.

The force acting on the droplet in the horizontal direction is shown in fig. 2(b). The dynamic equation is

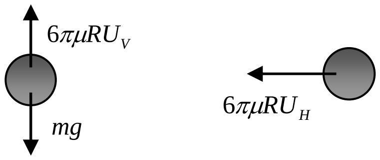
$$m\dot{U}_H = -6\pi\mu R U_H , \quad U_H(0) = v_{CR} \tag{2}$$

where, U_H denotes the droplet velocity in the horizontal direction. The solutions of the dynamic equations with the initial conditions are

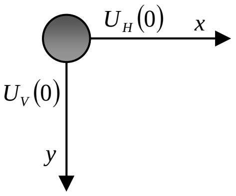
$$U_H(t) = U_H(0)\cdot e^{-\frac{t}{T_c}} \tag{3}$$

$$U_V(t) = g\cdot T_c + \left(U_V(0) - g\cdot T_c\right)\cdot e^{-\frac{t}{T_c}} \tag{4}$$

where, $T_c \equiv \dfrac{m}{6\pi\mu R}$.



(a) Vertical direction (b) Horizontal direction



(c) Coordinate system and initial values

Fig. 2 Coordinate system and forces acting on droplet

3. IMPACT POSITION CONTROL VIA FIRE STROBE TIME CONTROL

3.1 Fire strobe time control

Correct positioning of the injected droplet on media is one of the key factors determining the quality of printed image. A dot on media is formed with the droplet injected by the strobe signal synchronized with the encoder pulse generated at every 1/150 inch carrier movements. The impact position of droplet on media is determined by the injection time and the carrier speed at the time of injection. Since the conventional strobe signal is generated at the time after fixed delay from the edge of the encoder pulses, the impact position of the droplet on media is mainly affected by the carrier velocity at the time of injection. Thus the fluctuation of carrier speed deteriorates the correct positioning of the droplet. Moreover, at the state of carrier acceleration and deceleration movement to start and stop, printing is impossible due to the image distortions caused by the speed difference with the steady state velocity, which waste the printing time and space in the ink jet printer.

In this paper, the injection time is controlled to compensate dot placement error caused by the carrier velocity fluctuations. The strobe time to compensate the predicted dot placement error is calculated based on the estimation of the droplet flight distance.

The horizontal position $x(t)$ and the vertical position $y(t)$ of the droplet can be obtained by the integration of the droplet velocity trajectories with time.

$$\begin{aligned} x(t) &= \int_0^t U_H(\tau)d\tau \\ &= U_H(0)\cdot T_c \cdot \left(1 - e^{-\frac{t}{T_c}}\right) \end{aligned} \tag{5}$$

$$\begin{aligned} y(t) &= \int_0^t U_V(\tau)d\tau \\ &= g\cdot T_c \cdot t + \left(U_V(0) - gT_c\right)\cdot T_c \cdot \left(1 - e^{-\frac{t}{T_c}}\right) \end{aligned} \tag{6}$$

The flight distance of the injected droplet in the carrier movement direction during the droplet flight from nozzle plane to media plane can be calculated from the vertical and horizontal position trajectories and the head gap H_g .

$$x(t_p) = U_H(0)\cdot T_c \cdot \left(1 - e^{-\frac{t_p}{T_c}}\right) = H_g \cdot \frac{U_H(0)}{U_V(0) - gT_c} \tag{7}$$

where H_g means the distance between nozzle plane and media plane. Thus the predicted dot position error is obtained from the estimated flight distance and the carrier velocity.

$$d_e = \frac{H_g}{v_{drop} - g\cdot T_c}\left(V_{ss} - v(k)\right) \tag{8}$$

where, V_{ss} is the reference carrier velocity at the steady state and $v(k)$ is the carrier velocity at the time of encoder edge.

Based on the prediction of dot position error, we can calculate the delay time to compensate the position error by

$$t_d = \frac{H_g}{v_{drop} - g\cdot T_c}\cdot\left(\frac{t_p(k)}{t_{ref}} - 1\right) \tag{9}$$

where, t_{ref} and $t_p(k)$ represent the time intervals between adjacent encoder edges when carrier is moving with the velocity V_{ss} and $v(k)$, respectively.

3.2 Injection time and impact position

The pulse signal generated from strip encoder equipped in the carrier is used to provide the absolute carrier position and the reference time to fire. The pulse is generated at every 1/150 inch carrier displacements. Each period in the pulse is evenly divided to generate the reference signal to fire for the higher resolution of image. At the time instant $t = k$ when an edge of encoder pulse is detected, the next interval time $t_p(k)$ of the encoder period is predicted with the previous interval values $t_i(k), t_i(k-1), \cdots$, the predicted time interval

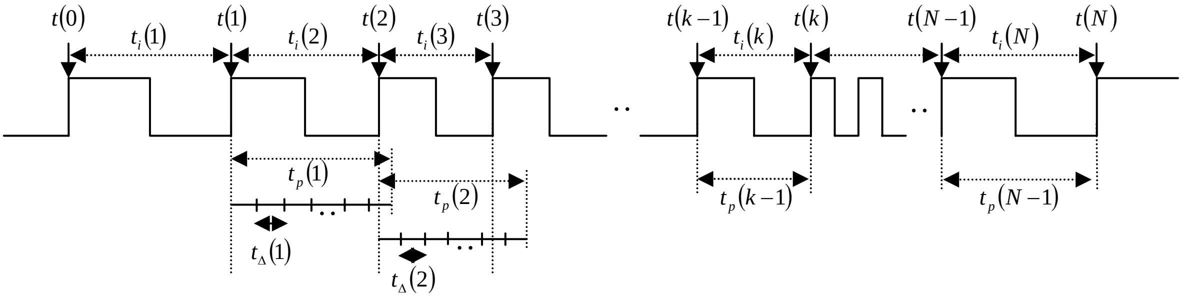


Fig. 3 Encoder pulse, Interval time and reference fire time

is evenly divided to generate the reference time for the injection fire strobe as shown in fig. 3. Ink droplet is fired at the time after the calculated delay $t_d(k)$ from the reference signal edges. Figure 4 show the relations between the time instants of encoder signal, the evenly divided fire reference signal and the delayed injection instants.

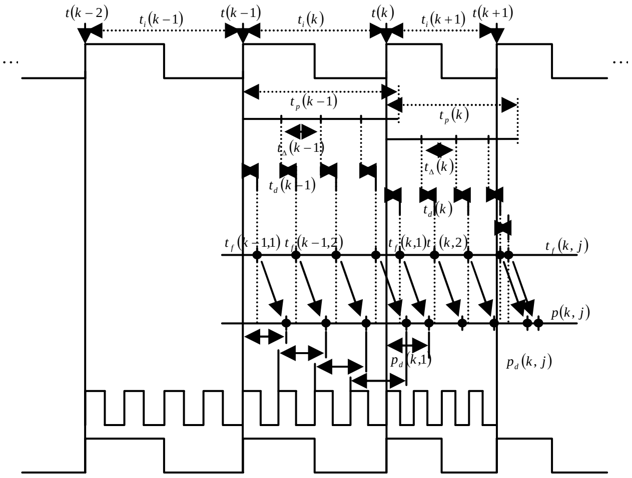


Fig. 4 Encoder pulse and the instants of fire to injection

The time instants of fire to inject the droplet is determined by

$$t_f(k,j) = t(k) + t_\Delta(k)\cdot(j-1) + t_d(k) \tag{10}$$

where, $k = 1,2,\cdots,N$ and $j = 1,2,\cdots,M$, and N means the number of dots to be printed in a line and M means the number of division 1/150 inch resolution encoder pulse signal.

To estimate the impact position of the injected droplet on media, the carrier position and velocity at the time of injection is estimated as

$$p_f(k,j) = \begin{cases} p(k) + t_d(k)\cdot v(k,j) & \text{for } k = 1 \\ p(k) + \sum_{i=1}^{j-1} v(k,j-1)\cdot t_\Delta(k) + t_d(k)\cdot v(k,j) & \text{for } k \ge 2 \end{cases} \tag{11}$$

where, the velocity $v(k, j-1)$ is the linear interpolation of the adjacent velocities at the time of encoder edges.

4. SIMULATION AND RESULTS

In this simulation, the motion of the injected droplet is assumed to be a Stokes flow. The fact that the Reynolds number is less than 1 in most of the trajectory except in the region close to the nozzle validates that the assumption is reasonable for the droplet trajectory estimation.

The physical values used for simulating droplet trajectory are listed in the table1. Mass and radius of ink droplet were derived from the volume and density. Viscosity of air was calculate by

$$\mu = \rho\cdot\nu \tag{12}$$

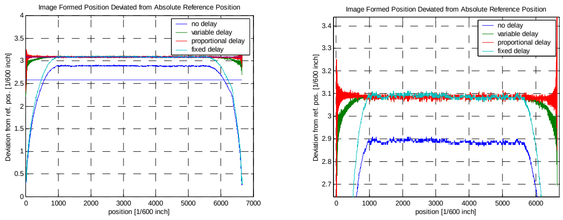
where $\rho = 1.29 Kg/m^3$ and $\nu = 1.5\cdot10^{-5} m^2/s$.

Table 1 Physical values of the simulated ink droplet

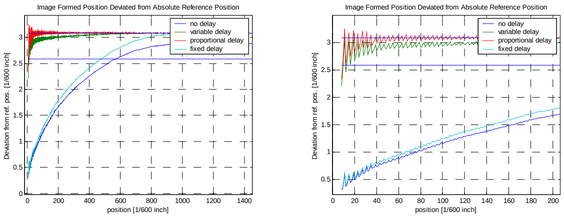
	V[pl]	m[Kg]	R[um]
Color ink	4.5	4.68e-12	10.24
	8	8.32e-12	12.41
Mono ink	30	31.2e-12	19.28

To verify the proposed fire timing control, the dot positions formed on media by injected ink droplet is simulated with various strobe time delay schemes. The simulation results compare the total flight distances of droplet including the movement during delay time, and the distances between adjacent dot positions whose command positions are distributed evenly.

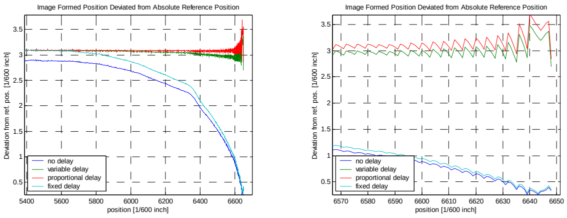
Figure 5 shows the droplet flight distances when the carrier is moving with 30 ips (inch/sec). Since the reference position of the flight distance is the position at the time of the reference encoder edges, the movement during delay time is included in the flight distance. It can be noted from the results that dot placement variations caused by the carrier acceleration and deceleration movement are successfully compensated by the proper injection time control. The dot positions of the controlled droplet are placed evenly during the carrier acceleration and deceleration movement whereas the injected droplets with no delay time control are placed at the increasing and decreasing positions proportional to the carrier speed. When the desired image dots are evenly distributed in the carrier movement direction, the printed image quality is determined mainly by the relative placements of the adjacent dots. The distances between adjacent dots are shown in fig. 6.



(a) Entire region (b) Entire region - enlarged

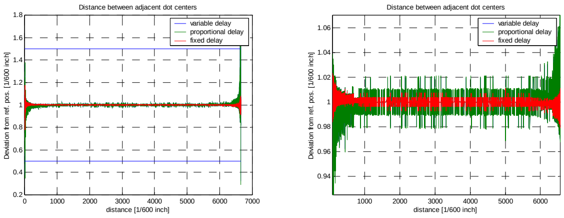


(c) Acceleration region (d) Acceleration region - enlarged

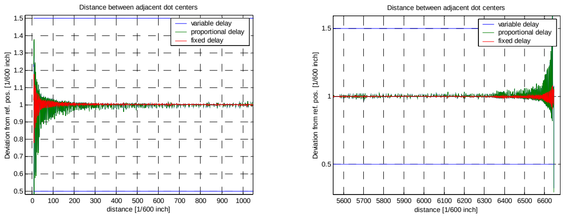


(e) Deceleration region (f) Deceleration region - enlarged

Fig. 5 Droplet flight distances



(a) Entire region (b) Entire region - enlarged



(c) Acceleration region (d) Deceleration region

Fig. 6 Distances between adjacent dot positions

5. CONCLUSIONS

In this paper, a position control scheme of the ink droplet was presented for the high image quality and print speed inkjet printer. The demand on image quality and print speed drives the inkjet printer to have printing ability even though carrier is moving with acceleration and deceleration speed. In order to print the image on the acceleration and deceleration states, the impact position errors caused by the speed gap between the acceleration/deceleration states and the steady state are required to be compensated by appropriate strobe time control scheme.

In this paper, the impact position was controlled by fire strobe time delay control that is calculated using the estimated carrier speed at the time of injection instant and the dynamic equations describing the trajectory of the injected droplet. To verify the proposed fire timing control, the dot positions formed on media were simulated with various strobe time delay schemes. The total flight distances of droplet and the distances between adjacent dot positions were compared to access the validity of the proposed control scheme. Compared to the simple strobe scheme with fixed delay, the proposed control scheme provided more accurate impact position control during the carrier is moving with accelerated or decelerated speed as well as constant speed. The accurate dot position control in the carrier's acceleration and deceleration states enables ink jet printer to save the printing time and frame space, which means the cost down.

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