Simulating the Deflection Plates in a Continuous Inkjet Printer

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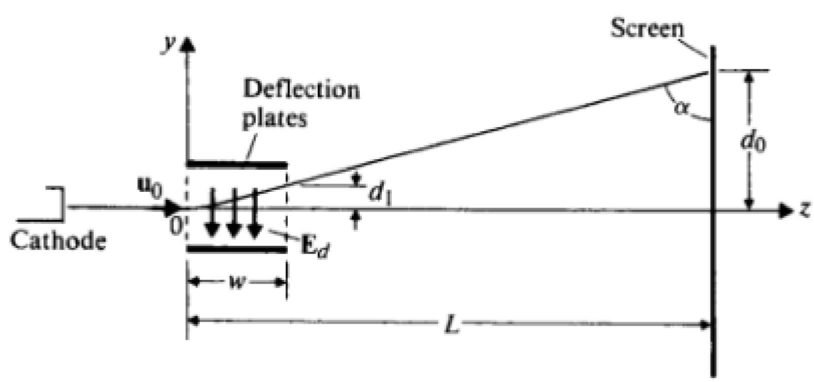
Introduction to Inkjet Printing

Since their invention, continuous inkjet printers (CIJP) have been used heavily in industry for precise marking on a variety of materials. The process of continuous ink jet printing can be broken down into three main steps. First, ink droplets are made from an inkstream that leaves a nozzle and is broken up via a piezoelectric oscillation. Second, the droplets are then charged through a charging electrode. Lastly, the charged ink droplets then enter another electrode with a deflecting electric field, accelerating the charged ink droplet into the desired location of the substrate. [2]



[1]

Fig. 1. Diagram of droplet deflection and equation dictating the distance d_0 from origin spot on the cathode, there d_1 is the parabolic trajectory of the droplet and d_2 is the linear trajectory after leaving the deflection plates.

In contrast, drop-on-demand printers (DODP) eject much smaller and precise ink droplets by using discontinuous, discreetly pressurized ink droplets. [3] CIJPs, however, are much faster, and therefore used for high speed packaging applications where DODP are more present in desktop printing, or applications that require precision.

In this paper, we demonstrate a simulation of the trajectory of ink droplets in CIJPs and the conversion of an image file into a printed image through varying electric fields generated by DC voltage waveform applied to the deflection plates.

Results

The first stage of the simulation was forming the corresponding electric field and current for the deflection plates to deflect the droplets to a given spot.

$$d0 = d1 + d2 = \frac{e*Ed}{m*u0^2} w(L - \frac{w}{2}) \ (1)$$

$$E = \frac{d0*m*u0^2}{[qw(L - w/2)]} \ (2)$$

$$V = \frac{dp * d0 * m * u0^2}{qw(L - w/2)} \quad (3)$$

Using the equation in Fig. 1, we can solve for electric field E and voltage V with a given d0, where d_p is the distance between the plates. In order to form the proper waveform, each individual point would have a corresponding electric field, which can then be used to calculate the corresponding voltage. The voltage at each point would then be stored into a single vector to be applied to the deflection plates. However, with the voltage waveform vector, there needs to be an indicator for the nozzle to make a line change after a series of droplets is deflected onto a single line. Therefore, 0 V in the vector indicates a line change, in which 0 V is applied. Given that each voltage change takes about 1 sec, the 0 V vector element would indicate a 1 second change per line. This would also mean that for n pixels before an actual line of ink, it would take n seconds to reach that line of ink.

Code

The full code is made in MATLAB and undergoes a process of finding a voltage waveform vector for an image. An image is inputted and translated into a matrix of dimension n-by-m-by-3, where n and m represent the height and width respectively, and the third dimension represents the 3 RGB values. Since the color values are unimportant, only the first dimension is viewed. This n-by-m matrix can be seen in Fig. 2. The image matrix is iterated through, searching for values less than the threshold value of 127.5. These spots indicate black spots. The corresponding column coordinates multiplied by a pixel length for each row is then used as the d_0 value to calculate the electric field using equation (2). The electric field matrix can be seen in Fig. 3.

255	255	255	255	253	255	251	245	244	255	253	255	255	255	255
255	255	255	255	255	228	129	66	91	193	255	254	255	255	255
255	255	255	255	255	194	68	28	38	135	244	254	255	255	255
251	255	255	255	247	150	38	80	42	91	219	255	255	254	255
255	253	255	254	225	93	53	176	58	56	181	253	255	254	255
254	255	255	253	200	56	102	232	129	39	136	242	255	255	255
251	255	253	255	132	58	156	248	189	54	74	220	254	255	255
255	255	251	239	78	75	203	255	224	96	39	181	248	253	254
255	255	255	177	56	111	235	252	248	146	38	106	237	255	254
250	255	245	104	52	166	248	255	251	194	63	50	199	255	254
255	255	204	66	65	187	227	231	231	207	95	29	150	244	254
254	254	150	40	43	80	86	87	89	82	52	26	88	224	252
255	232	102	27	45	50	51	53	50	48	52	31	55	185	255
250	187	66	54	193	224	221	219	222	223	213	92	40	134	240
244	141	43	119	231	255	253	255	255	249	255	161	48	91	217
227	93	31	180	255	254	255	251	253	255	255	223	61	48	179

Fig. 2 Image of the letter ‘A’ in matrix format.

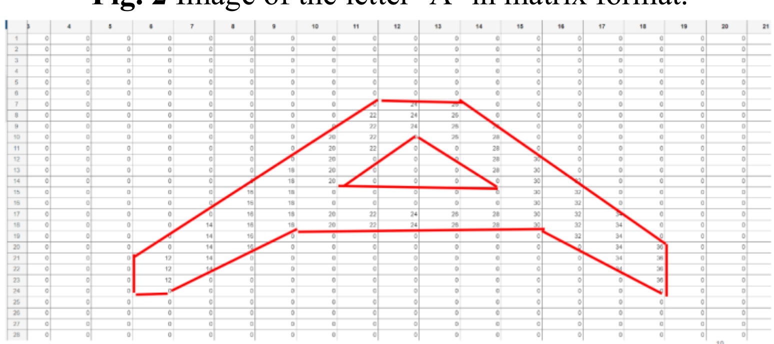


Fig. 3 Electric field matrix generated from the image matrix. Each value represents the horizontal electric field applied to a charged particle with the coordinate (0, y), where y is the column index.

After the electric field matrix is obtained, it is converted into a voltage waveform vector. Fig. 4 shows an example of this vector. The vector searches for values greater than 0 and then calculates the corresponding voltage value by multiplying the electric field element by d_p, the distance between the two deflection plates. Additionally, each row on the electric field matrix, 0 is appended to the voltage waveform vector. In doing so, a line switch is indicated simply by detecting the value of 0 V in the voltage waveform.

```
V = 1×102
     0     0     0     0     0     0    24    26     0    22    24    26     0    22    24    26    28
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Fig. 4. Voltage Waveform Vector

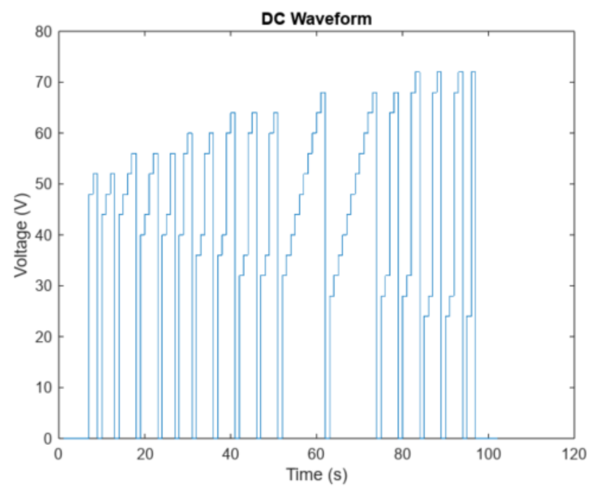

Fig. 5. Voltage vs. Time graph of the DC Voltage Waveform, displayed in a stair graph. This represents the voltage applied across the deflection plates as a function of time.

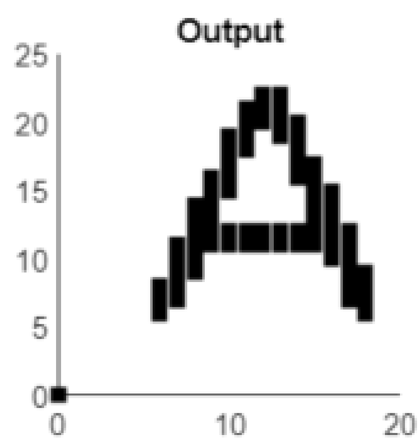

Fig. 6. Graph of ink output on the substrate. Each value on the y-axis represents a line on the substrate that is printed. The output image corresponds to a DC voltage waveform that dictates the target destination for each ink droplet.

Code Outputs

Using the voltage waveform vector, equation 1 is used to determine the distance from the column index of 0 on each row with a given vector. The output is a 2-by-x output image matrix, where x is the length of the voltage vector. For each value on the voltage waveform vector, the corresponding distance, determined with equation (1), is then calculated on the first row. On the second row, an index tracker is initialized at the value of the voltage waveform vector length. The index tracker then decrements for each 0 detected in the voltage waveform vector. This index tracker is then appended to the second row of the output image matrix everytime the vector waveform vector has a value not equal to 0. In doing so, the output is then a two row matrix that contains x values on the x axis and y values on the y axis. This output is seen in Fig. 6, and represents the printed output on a given flat substrate.

Additional Features

The two additional features are purely visual. The first is a static image of both the voltage waveform vector and the output image matrix. The voltage waveform vector is displayed in a voltage vs. time stair plot with discrete voltages applied for each ink droplet. The time is simply determined by representing each entry as a single second. The voltage waveform vector, visually indicates when a new line is started as the voltage is dropped to 0 V for a 1 second. In the output image matrix, the full image is displayed by iterating through the output image matrix, with the first row as the x values and the second row as the corresponding y values. The output image matrix is displayed as a xy-scatter plot with each point as a black box, which is then filled in to complete the picture.

Another additional visual feature included was a gif animation. This was simply done through looping through the columns of the voltage waveform vector and the output image matrix simultaneously. Since these two have the same number of columns, they can be looped through in the same for loop. The exportgraphic() function is called each loop and updated in order to create a changing image. This image would then be saved into a .gif file.

Conclusion

With MATLAB, we were able to simulate the full process of obtaining an image, breaking down the image into rows, determining the needed electric field to deflect a charged droplet into a desired position, and obtaining a corresponding waveform for that full image. This process demonstrates how DC voltage waveforms can be obtained through an image, which can then be applied into deflection plates in a CIJP. A few assumptions were made in the process. Fundamental constants, such as pixel length, droplet-to-substrate distance, and deflection plate distance, were initialized to 1. These values can be changed to actual values for actual CIJPs in order to simulate a true output. Additionally, the other factors, such as ink droplet charge and droplet size are assumed to be constant. These calculations would require an analysis of the piezoelectric oscillations in the printhead and is beyond the scope of this paper.

References

[1] D. K. Cheng, *Field and Wave Electromagnetics, Second Edition*. Reading, MA: Addison-Wesley Pub. Co., 1989.

[2] M. Ikegawa, M. Ishikawa, E. Ishii, N. Harada, and T. Takagishi, “Ink-particle simulation for continuous inkjet type printer,” *NIP & Digital Fabrication Conference*, vol. 31, no. 1, pp. 13–18, 2015. doi:10.2352/issn.2169-4451.2015.31.1.art00006_1

[3] T. Otowa, S. Tsubouchi, and Y. Suwa, “Analysis of the ink-stream break-up phenomenon in continuous inkjet printing,” *ACS Omega*, vol. 8, no. 38, pp. 34442–34447, 2023. doi:10.1021/acsomega.3c02790