Dynamic Ink-Jet Printing Analysis System with Addressable Waveform Trimming

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Abstract

Definitely the ink-jet fabrication is an expectable technology for the fields of display and semiconductors, such like for the fabrication of color filters, the forming of metal circuits, the dispensing of liquid crystal, and for the further continuous manufacture of flexible displays etc. Recently, inkjet printing technologies have been rapidly developing and are not only for the diminished size of the drops to the pico-liter, the multiplex driving scheme, or for the real-time observation technology which led to the improvement of the inkjet printing performance, and which realized the pixel-to-pixel control. In this article, an electrical controller is designed to differentiate the waveform for each nozzle synchronously, to compensate for the nozzle cell deformation and pressure drag loss during inkjet firing at high voltage, and for a high frequency named addressable waveform trimming circuit (AWTC). The controller is composed of a high voltage control block which drives each nozzle, an FPGA chip to multiplex the high voltage output, an A/D converter which transfers an analog signal into a digital signal and then into FPGA, a differential signal input to FPGA as feedback to correct analog output, which gives a real-time tracking of jetting quality to verify the nozzle-to-nozzle variation. For dynamic feedback of the drop variation in real jetting, this AWTC accepts correction signals by a machine vision system synchronously with the firing trigger in order to analyze the individual captured images. The maximum support nozzle channel is up to 1280 and can be handled within a 2% jetting accuracy.

Introduction

Because of the need for light, flexible, and thin electronic products, the research cycle for electronic products has been shortened; therefore, the easily varied manufacturing process is maturing. The printing technology, especially for digital fabrication methodology, like ink-jet printing, liquid toner, and laser writing, which require

precise and fine patterning technology, are used by the electronic industry as a major stream technology for the next generation of the manufacturing process.

Certainly, inkjet technology has rapidly improved in recent years; however, there are still some difficulties for inkjet technology in the electronic industry at the present time. For example, the LCD industry claims that the volume of drop size is critical., In general, a variation around ±10% is the basic request. In addition, the reliability confidence is still a major challenge today because of the difficulties in monitoring the drop landing behavior, film drying, and the interface behavior between the liquid-solid interface environments. Because of the lack of these real physical descriptions, the control methodology, including the driving modulation, pressure stability, and temperature feedback, are difficult to precisely design today.

In this article, following prior research by Ou etc. [1], we try to accurately control the behavior of dispensed drops at an extremely tiny scale with a dynamic analysis assistant, named Addressable Waveform Trimming Circuit (AWTC). . The AWTC system includes a pressure source control unit and a hardware driving circuit. Furthermore, an additional optic observing mechanism assisted by the image processing software is also combined with the AWTC. The whole framework makes it possible to tune the rising time, the holding voltage, and the falling time of a driving waveform, which are applied to every appointed piezo-electronic print head. In hardware design, each driving circuit controls one actuator, the piezo actuator of the nozzle, which is corrected as a cluster unit in the 64 driving circuit. The maximum driving capacity is up to 1024 nozzles for one single board. As mentioned before, the environmental conditions are fed back to this main board via the analogy channels, where it 'realizes' with an A/D chip that it should convert the feedback signals to FPGA. Besides, the real drop jetting information, the drop velocity, and the volume variation for each nozzle, is captured by the high speed linear scan CCD array as waveform tuning feedback which is used to modulate the nozzle-to-nozzle variation.

By using the multiplex circuit architecture, this FPGA driving control system can modulate up to 1024 nozzles. For multiple print head applications, this design can smear the head-to-head difference in real-time, by the DSP core processing unit. This mechanism can accept the analog differential error inputs, like the drop velocity, drop volume, temperature variation, and pressure variation, as does the real-time feedback control according to said inputs. This control mechanism is capable of exhibiting perfect jetting behaviors within 2% variation between different nozzles.

Experimental Setup

AWTC Driving System

The main function of an AWTC driving circuit is to control an 125MHz digital counter in order to determine the charging and discharging period of a piezo-electronic nozzle which is normally equivalent to a capacitor component in the circuit. Since there are different lengths of the charging and discharging period, it is possible to generate a waveform with different rising and falling times. The driving pulse pattern is shown in Figure 1. By trimming period T1, T2, and T3, and the holding voltage VH, the velocity and volume of drops is therefore easily modified by the user. From basic micro-fluidic behavior, the T1 is the period of time that the mechanic energy transfers into liquid jetting energy. A long T1 will foster a faster drop. The T2 and VH, determine the growing of the drop volume. When the drop finally will break-off depends on the condition of T3. Figure 2 shows the hardware board of AWTC system.

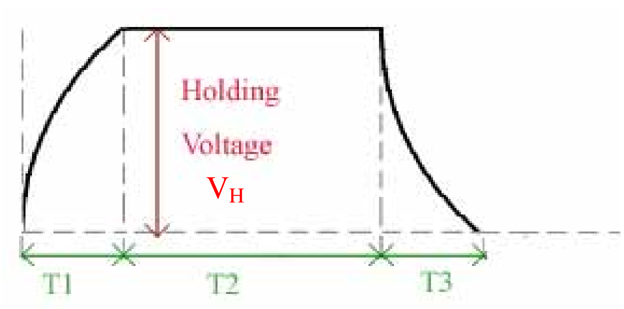


Fig. 1: The waveform and parameter T1, T2, T3, and VH is for the AWTC to drive and trim the piezoelectric nozzle.

Besides the circuit parts, the objective components of AWTC are also specially chosen. For keeping the objective system away from the dispensing drops, an observing setup which has an extra long working distance is essential, especially when eroding solvents are used. In addition, since the AWTC system is created to eliminate the variance between drops with a 2% size tolerance, its optical magnification power must be large enough to meet our needs. Long working distance and large magnification are the two basic requirements of AWTC.

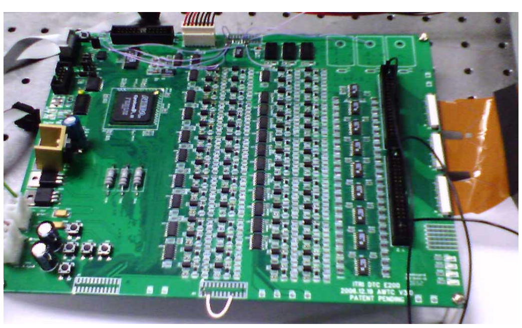


Fig. 2: The picture of the AWTC circuit board.

Drop Observation Interface & Functionality

The optical system mainly consists of a line scan CCD array, the optical magnifier tube, and a digital image capture interface. However, long working distances and large magnification are a physical trade off in an optics system limit. Therefore, AWTC selects a combination group of lenses in order to achieve a 10cm working distance and an optical magnification power of 60X with a VGA CCD camera and a software controlled LED strobe. In this design, it is possible for each CCD pixel to analyze a 0.4um optical resolution in the target object. The appearance of the AWTC experimental setup is shown in Figure 3.

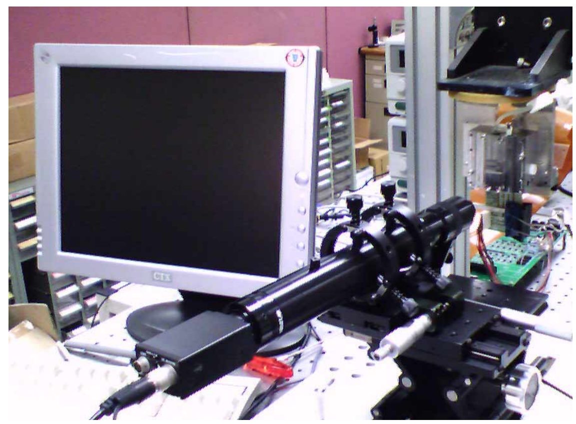


Fig. 3: Appearance of AWTC system combined with optical observation.

Within the characteristics mentioned, software master all-trimming routine for the AWTC system is successfully developed. This AWTC software is developed in labVIEWTW language and connects the AWTC board through a PC common port and a USB port. By adjusting the delay time between the driving waveform of the piezoelectric print head and the LED strobe, images of the flying drops are captured stopped in frame, and the captured image data are transferred through the DNC cable to the IMAQ card on the PC. An assistant image processing tool, NI Vision, is also applied to the analysis of the drops.

Nevertheless, there is still one thing to keep an eye on, that is, an accompanying lack of sharpness because the high working distance and the magnification demand entail some noise and dimness when the CCD camera captures the image. Therefore, a software filter must be applied when the image is processed in order to measure the drop size and velocity. The mathematical calculation must be fast enough to compute the behavior of drops continuously.

Image Enhancement & Processing

AWTC software offers users an easily modified interface in which to drag a rectangle as a focused zone and to localize the position of the drop in a captured image. Image analyzing processes are only applied in this focused zone, so the influence of environmental noise could be roughly excluded by the user. After performing a grayscale numeric drop analysis of the image in a focused rectangular zone, mass neighbored pixels with a small number of grayscale of precisely black color, is defined as the drop composition. Since the length of each pixel is 0.4um, a summation of the quantity of pixels performed by the software is further computed. Results in the physical area of the drop and the volume of drop can be immediately obtained via the convolution operation along with the jetting direction.

In this paper, the chosen print head generates drops of about 10pL volume. Because of the difficulties of directly observing the tiny drops, the sizes of drops are usually determined by computing the flying velocity first, and then comparing the velocity to the velocity-volume curve [2]. However in this AWTC system with this observation system with high optical resolution up to 0.4um discrimination, the captured drop size can be accurately calculated.

Figure 4 (a)-(c) is the real captured image depicting the discharged drop with this AWTC & observation system. The analysis of the volume and the velocity of the drop are shown in the column that offers a real time analysis function. Figure 4 (b) and (c) are the images of the function that shows how a drop is distinguished from the image frame.

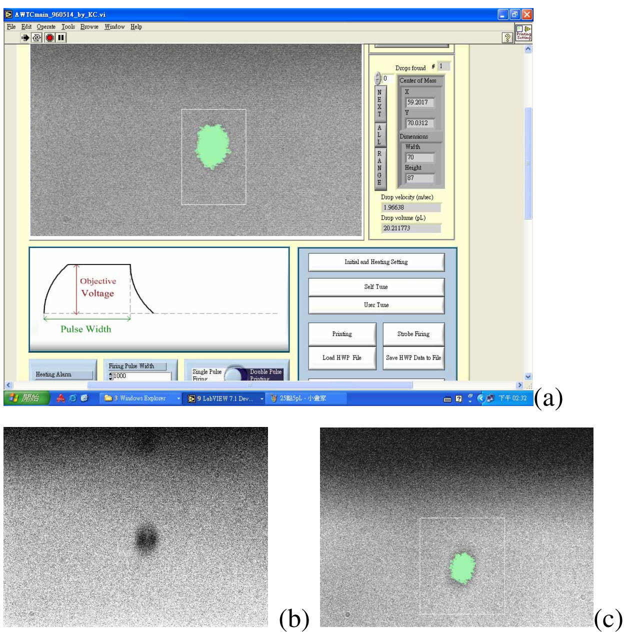


Fig. 4 (a)-(c): Image captured by the observation system: (a) Software interface & functionality (b) an example of capturing an original image for a 10pL drop (b) an example of how the image at (b) had proceeded & had been identified

Discussion & Conclusion

The ability to dominate the drop size

The history of a drop from jetting to landing can be continuously recorded by adjusting the observation timing. It can operate at up to an 8 ns timing change in depicting the drop trajectory, as indicated in Fig. 5(a)-(d). In waveform modulation, the driving condition is set on an increased rising period T1, then the holding voltage period T2 is maintained at 10.1us, and the discharging period T3 is kept as 3.5us. The gradual trimming makes both the rising period T1 and holding voltage VH larger step by step with the outcome influenced in dispensing the drop as shown in Figure 5.

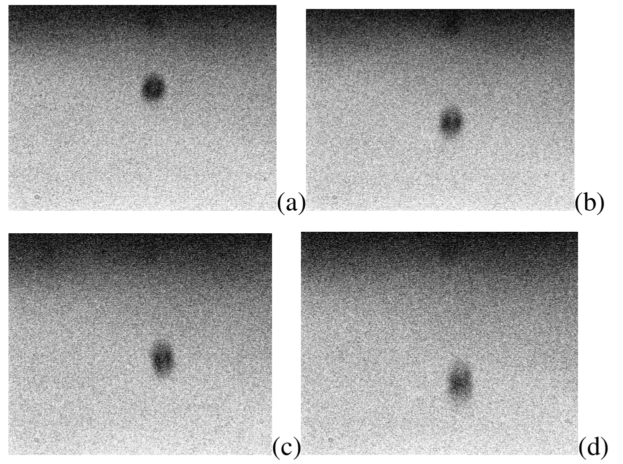


Fig. 5: (a), (b), (c), (d) Pictures of results of tuning different charging times. (a) T1=1.70us (b) T1=1.88us (c) T1=2.06us (d) T1=2.23us

Generally, in order to get a perfect jetting quality, one also must be concerned with the variation in drop velocity. It is determined by studying the observation time and then calculating the image shift between the different observation images. Because of the synchronization of the driving pulse and the LED strobe pulse, the same positions of the drop in the image can be captured and stopped with a synchronous light source. Whenever the strobe delay period is elongated, the position of the drops changes at the same time. Then the velocity of the drop is calculated so that the distance of the drop position is divided by the amount of the delay time. The AWTC software returns the drop velocity immediately when the charging time of the driving waveform changes. Figure 6 shows the influence of different strobe delay time, and in these figures, the drop size remains constant and only the position of drop differs.

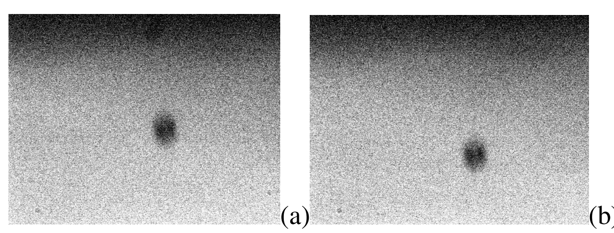


Fig. 6 (a), (b): Tuning the strobe delay time with the same charging period

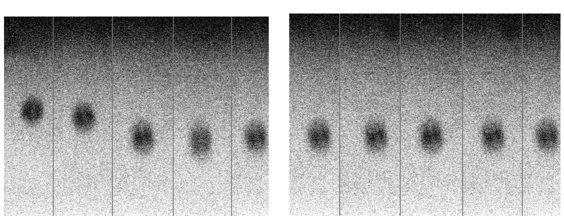
A brief table of experimental results is rearranged in Table 1. This data presents that the AWTC system could nonlinearly control the velocity and volume of any single drop. This experimental result further tells us that if the rising time of a waveform increases 0.045us, then the size of drop increases by 1.96%, or roughly 2%. The 2% analyzing limit is caused by the optic observing system and causes the addressable waveform trimming circuit to yield and to match up with the limitation. In other words, there is still a possibility for the AWTC system to tune in only 0.008us, equally 8ns, of the charging period in order to analyze and control a drop variance smaller than 2% if an improved optical objective system is attached.

Table 1: Different Drop behavior under application of different AWTC trimming parameters

T1	Holding voltage	Volume (pL)	Velocity (m/sec)
1.70us	40.2V	11.09	1.43
1.79us	41.4V	12.38	1.69
1.88us	42.6V	13.61	1.96
1.97us	43.5V	14.29	2.31
2.06us	44.6V	15.28	2.43
2.15us	45.6V	15.43	2.54
2.14us	46.1V	16.26	2.64
2.23us	46.8V	17.02	2.77
2.32us	47.8V	25.28	2.88
2.41us	48V	27.26	2.96

The ability to eliminate variance between nozzles

The AWTC driving with an observation system, can correct the variation behavior which exists between nozzles in real-time. Fig.7 (a)-(b) compares the jetting condition with and without feedback control. Fig. 7(a), shows the drop jetting from nozzles with an obvious timing-lag and volume difference. After the driving is corrected by AWTC, the jetting drops can be aligned in a perfect zero timing-lag, and the volume variation can be kept within ±2%. In this paper, we successfully combine the AWTC driving and the real-time observation as a feedback basis in order to achieve highly accurate jetting control. The drop with a variation less than 2% is feasible, and the maximum capacity is up to 1024 nozzles in support. This new ink jet control technology is expected to be used in new industrial applications, in the LCD, in semiconductors, and in the printed circuit board field in the near future.



(a) (b)

Fig. 7: Addressable waveform trimming function of the AWTC causes a coincidence of drops from different nozzles. (a) In an original firing situation, variation exists between nozzles. (b) After receiving the analog feedback from optical observation & the difference between nozzles, the driving corrects the nozzle-to-nozzle variations.

Table 2 shows the detailed trimming parameters and results of Fig. 7. Because of the variance between nozzles, even if the same magnitude of voltage at 42.0V, in the first column of Table 2, is initially applied to the neighboring five nozzles, these dispensing drops show different behaviors indeed and form different drop sizes in Fig.7 (a). After AWTC trimming, these drops form the same volume, around 14.80pL as shown in Fig. 7(b) and the fourth column of Table 2. It is clear that the final tuned holding voltages in the third column of Table 2 are different from one another, but the volume variance in the fourth column of Table 2 are eliminated below 2%.

Table 2: Resulting Unity Behavior of Drops after AWTC Trimming

Holding voltage (a)	Volume (pL) (a)	Holding voltage (b)	Volume (pL) (b)
42.0V	11.09	45.4V	14.80
42.0V	12.38	44.9V	14.76
42.0V	14.82	42.0V	14.82
42.0V	14.83	42.0V	14.82
42.0V	14.79	42.3V	14.79

The results mentioned above show that the AWTC system finely controls the inkjet dispensing behavior and provides a nonlinear controlling trimming process which achieves the needed 2% variance. The nonlinear property during different voltage supply zones could be the focus of future research work.

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