Expanding Capabilities of a Machine Vision System for Analysis of Drops-in-flight

Y. Kipman, P. Mehta, E. Nguyen and S-W. Wang

ImageXpert Inc. 460 Amherst Street, Nashua, NH 03063 USA, ix@imagexpert.com

ABSTRACT

Measuring in-flight characteristics of ink drops under different conditions can aid in optimizing system settings, ink formulation and printer performance. Droplet analysis can provide insight into possible relationships and interactions that can help drive system and consumable optimization for manufacturers of ink jet heads, head driver electronics, inks, and integrated printing and material deposition systems.

Previous papers have discussed JetXpert, ImageXpert's integrated, machine-vision system for the measurement of drops-in-flight.

Developers and researchers are often hampered by the overhead required to test print heads including procuring appropriate drive electronics and ink delivery systems. And, there is the ongoing push to improve efficiency by decreasing operator time necessary for data collection.

In order to expand the capabilities of the JetXpert system, ImageXpert has developed a "universal" ink delivery system for use with nearly any print head to allow for more efficient and cost effective evaluation of print head performance.

And, by using one axis of automated motion for automatic sequential inspection of each jet across a print head, inspection time and costs can be minimized. Droplet characteristics include drop trajectory, velocity, radius and volume, as well as other features as desired. Volume of drop series and ligaments can also be reported.

This paper will give an overview of the JetXpert system including the motion option, and detail the newly developed ink supply system.

Keywords: Inkjet, drops-in-flight, drop volume, drop watcher

1 INTRODUCTION

An integrated, machine-vision system, JetXpert, has been developed for the visualization of faceplate wetting and the measurement of drops-in-flight. [1], [2]

For analysis of drops in flight, the system combines a high-powered LED strobe and control electronics, a camera, specialized optics and ImageXpert software to provide a flexible platform for analyzing the performance of any print head. The strobe is linked to the firing frequency of the print head, so while it is synchronized, it is independent of the specific print head being inspected.

2 SYSTEM OVERVIEW

In the JetXpert system, the strobe is slaved to the firing frequency of the print head or non-contact dispensing system via a TTL signal. This flexibility makes the system able be used to measure drops-in-flight for any print head where drops are in free flight and a firing signal is accessible via print head electronics or an external frequency generator.

The strobe interface software provides digital control of strobe pulse width (with a very short minimum pulse width: 125ns, with standard operation at 500ns); imaging of single or double drops with multiple delay times; and strobe intensity for optimal imaging for a variety of print heads and jetted materials. In addition, the strobe control software and the high-powered LED strobe allow for single event strobing, one strobe per image frame, which allows for single droplets to be imaged and analyzed.

The proprietary optical design allows for imaging and analysis of drops less than 2 picoliters in volume.

ImageXpert image analysis software is used for droplet analysis including drop trajectory, velocity, radius and volume, as well as other features as desired. Volume of satellites, droplet series, and ligaments can also be reported.

The optical system is calibrated using a precision slit, and the software returns calibrated results from droplet analysis in real-world units such as picoliters and meters/second.

For print head wetting, the system uses a camera and light source set at an angle to view ink buildup and wicking on the faceplate during firing. This second camera is useful for assessment of faceplate wetting during use, for both run wet and run dry systems.

Figure 1: JetXpert system image showing second camera for faceplate viewing, computer and strobe control box (with mouse for scale)

2.1 Strobe Control User Interface

The LED strobe is essential for successful image capture. The strobe control electronics are set up and controlled via a user interface. The strobe control graphical user interface allows for selection of pulse type (single or double), pulse width and delay times, along with LED intensity and camera shutter speed. The strobe settings also feed directly into image analysis by providing current values of specific variables such as delay times that are used for calculations.

Figure 2: JetXpert strobe control user interface (GUI): Standard Tab

The interface also allows for calibration, image capture, image analysis and data collection, as well as image and movie capture and saving.

2.2 JetXpert Synchronization

The JetXpert strobe is triggered by an external signal from a print head driver or signal generator, with the actual characteristics of the strobe (pulse types, delay times, intensity, duration) determined based on settings in the GUI.

Both strobing and image capture are initiated by the receipt of a firing signal from the print head electronics.

Delay 1 defines the time between the receipt of the firing signal and when the strobe is actuated. Delay 2 is relevant for the two-drop (double drop) mode, where the strobe fires twice after receiving the print head firing signal, imaging the same droplet at two different times (Delay 1 and Delay 2) and therefore two different distances from the print head. The image captured, then, shows the two instances of the drop at different distances from the print head.

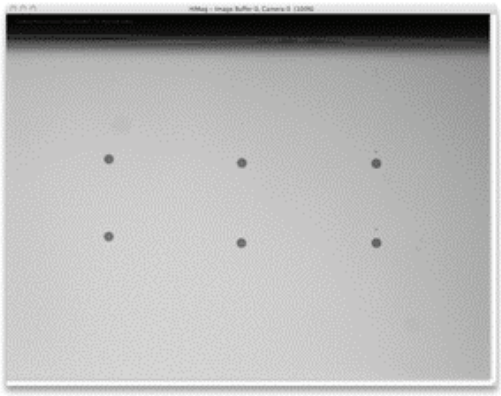

Figure 3: Double-drop image

If a strobe delay (the delay time between the firing signal and the strobe actuation) is longer than the firing frequency, there will be some firing signals during the delay that will not be used to trigger the firing of the strobe or initializing the strobing sequence. These intermediate firing pulses are ignored.

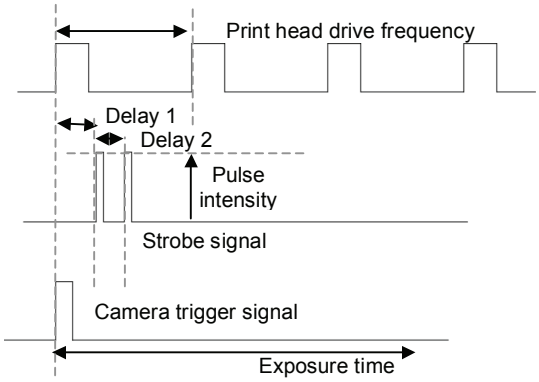

Figure 4: Conceptual sketch of a double drop (two strobes, two delays) signal relationship between print head firing frequency, the camera, and the strobe, assuming a rising edge trigger.

2.3 Single Strobe vs. Droplet Aggregation

JetXpert uses one single strobe per droplet location per image frame allowing for imaging and analysis of single droplets or droplet streams (this is called single event imaging).

This is unlike other technologies that have multiple firing and strobing instances in a single frame, which results in aggregation of droplet images in each location. Since there is often some level of system instability that results in micro variation in droplet position, aggregation can cause blurring of the droplet image as shown in Figure 5.

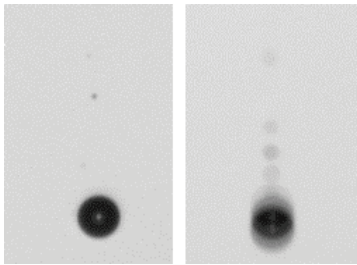

Figure 5: Single event image of droplet (left) versus 4 drop aggregated droplet image (right). Both images were taken with a strobe pulse width of 500ns.

2.4 Pulse Width and Blur

Changing the strobe pulse width also has an impact on image blur due to the motion of the droplet during the strobe pulse. A longer pulse width means there is more time for the droplet to move during strobing. So when droplets are traveling quickly, the movement of a droplet during the strobe can cause appreciable blurring of the droplet image as shown in Table 1 and Figure 6:

	Blur (in mm) at droplet velocities of:		
strobe pulse width (ns)	5 m/s	10 m/s	15 m/s
125	0.000625	0.001250	0.001875
250	0.001250	0.002500	0.003750
375	0.001875	0.003750	0.005625
500	0.002500	0.005000	0.007500
625	0.003125	0.006250	0.009375
750	0.003750	0.007500	0.011250
875	0.004375	0.008750	0.013125
1000	0.005000	0.010000	0.015000
1500	0.007500	0.015000	0.022500
2000	0.010000	0.020000	0.030000
2500	0.012500	0.025000	0.037500

Table 1: Calculation of blur vs. Pulse width for different droplet speeds

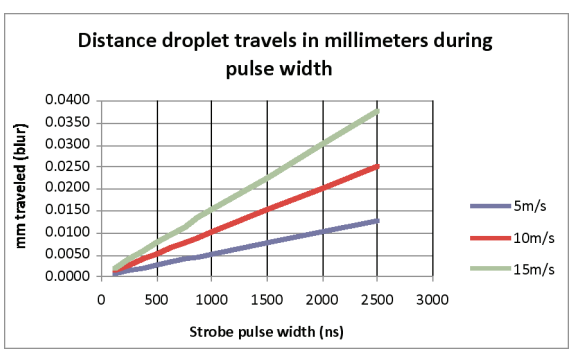

Figure 6: Graph showing the relationship between strobe pulse width and droplet blur

3 PRINT HEAD CHARACTERIZATION

Print head characterization is possible by using one axis of automated motion for automatic sequential inspection of each jet across a print head. Automating this process decreases inspection time and, therefore, the costs associated with inspection can be minimized as well. Droplet characteristics include drop trajectory, velocity, radius and volume, as well as other features as desired.

3.1 Automation

Automation is enabled using one automated axis of motion. Motion control is available through the underlying ImageXpert software, to enable automated "scripts" that step across the print head for example, capturing images of drops-in-flight from each nozzle, performing analysis on those images, and saving relevant data.

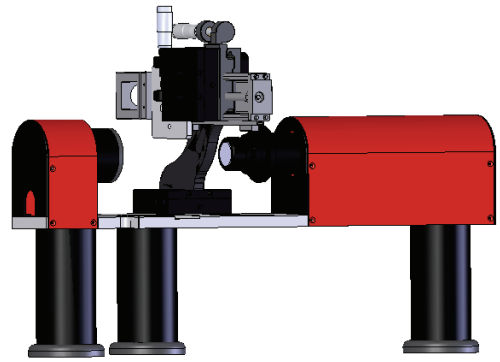

Figure 7: JetXpert system sketch showing lateral motion stage to automatically move print head in front of camera (on right) for sequential analysis of all jets on a print head for print head characterization or tuning

The one axis of automated motion (two other axes are manually adjustable has a range of motion is about 5" in the standard configuration.

Combining ImageXpert's motion control, automation capabilities, and drop analysis algorithms, an automated motion stage can increase measurement efficiency by allowing for full print head characterization and optimization.

For example, some print heads have tunable voltages per section or nozzle, so having objective and quantitative feedback about actual performance of each jet can allow for on-bench tuning and optimization.

3.2 Frequency sweep

ImageXpert also offers a frequency sweep capability as an add-on to existing JetXpert systems or as an option when purchasing new systems.

The JetXpert software sends commands to a programmable signal generator, defining frequency, and the signal generator then triggers the print head drive electronics. The JetXpert can be triggered via the signal generator or via a copy of the firing signal of the print head for synchronization.

By integrating the control of a signal generator into the JetXpert software, the system can automatically step through a range of actuating frequencies as specified by the user in a settings file, and the system can be used to assess the impact of firing frequency on fluid behavior (velocity, volume, repeatability) and print head performance with minimal operator intervention.

JetXpert includes a Frequency Editor window for the user to load a pre-defined file or to edit or create a new one. The frequency settings file includes a list of frequencies that will be called in order with a single instance of image capture and analysis at each step. Figure 8 shows an example of the frequency editor window.

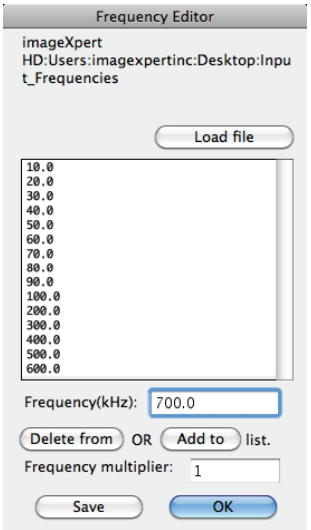

Figure 8: Frequency Editor Window

JetXpert uses a proprietary method to determine the most appropriate analytical method for droplet measurement (specifically, for determining the appropriate method for calculating droplet velocity). Selection is based on the firing frequency and a priori knowledge of the impact of frequency on droplet spacing in the images captured using the JetXpert system.

4 UNIVERSAL INK SUPPLY SYSTEM

In R&D, many companies explore many different print heads to validate their jettable fluids or to select the most appropriate print head for their application.

Many makeshift ink delivery systems have been used, including syringes and other low tech or manual feed methods.

To help minimize startup times in R&D, and to decrease complexity and changeover time when moving from one print head to another, ImageXpert has developed a universal single color ink delivery module that works with both aqueous and UV curable inks. The ink supply system was designed such that the meniscus level remains constant while printing.

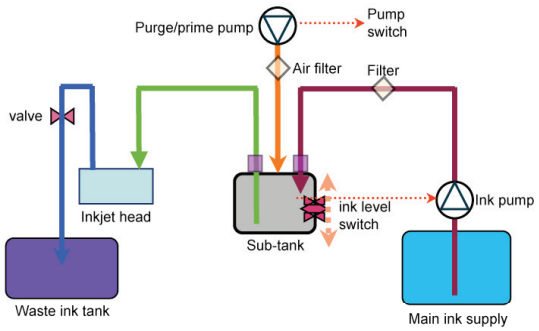

Figure 9: Universal ink supply system diagram

This fully integrated ink delivery system is available as a stand-alone unit, or as an add-on to new or previously purchased JetXpert systems.

5 CONCLUSION

The JetXpert system is in widespread use for the analysis drops-in-flight, which can provide insight into possible relationships and interactions that can help drive system and fluid optimization for inkjet technology-based system developers and manufacturers.

By expanding the capabilities of the system to include automation and a universal ink supply system, the utility of the system expands as well- decreasing inspection time and costs, and decreasing overhead by limiting the need for operator interaction and minimizing changeover times.

In R&D, the ability to assess performance over multiple frequencies without operator intervention can help improve print head performance and/or improve fluid formulation for optimal system performance.

Expanding access to quantitative data allows more companies to assess their jetting system stability and verify performance.

REFERENCES

[1] Yair Kipman, et al, "A strobe-based inspection system for drops-in-flight", Proc. SPIE Vol. 7242, 72420H (Jan. 19, 2009)

[2] Yair Kipman, "Machine Vision System for Analysis of Drops-in-flight and Wetting Visualization", Proc. Nanotech 2010 Vol. 2, pp 546 – 549