Machine Vision System for Analysis of Drops-in-flight and Wetting Visualization

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ABSTRACT

Measuring the in-flight characteristics of ink drops and visualizing faceplate wetting under different conditions can aid in optimizing system settings, ink formulation and printer performance. Manufacturers of ink jet heads, head driver electronics, inks, and integrated printing and material deposition systems can benefit from analysis of drops-in-flight.

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

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

This paper will give an overview of the details of this system as well as show some of the system capabilities through several examples of drop-in-flight analysis and faceplate wetting visualization.

Keywords: inkjet, ink, wetting, inspection system, drops in flight, drop analysis, drop visualization, drop volume

1 INTRODUCTION

Imaging and measurement of drops-in-flight often relies on the measurement system's ability to drive the print head directly in order to synchronize the strobe for repeatable image capture. In addition, many systems do not have the necessary combination of strobe control and image analysis for full drop-in-flight evaluation.

An integrated, machine-vision system, JetXpert, has been developed for the visualization and measurement of drops-in-flight [1]. The system combines an LED strobe and control electronics, one or more cameras, optics and ImageXpert software to provide a flexible platform for analyzing the performance of any print head.

2 SYSTEM DESCRIPTION

In the JetXpert system, the strobe is slaved to the firing frequency of the print head (50Hz - 100kHz) so it can be used to measure drops-in-flight for any print head. There is also an internal clock for triggering print head drivers that cannot provide an external signal.

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 dots 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.

Cameras are digital, Firewire, black and white and have 1024 x 768 pixels. The optical design allows for imaging and analysis of drops down to 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.

A second camera system is used for imaging of the nozzle plate during operation, which can provide insight into faceplate wetting and ink build-up during operation.

Figure 1 shows the two-camera system.

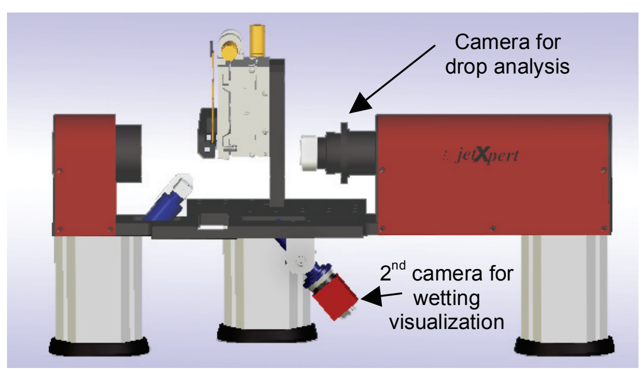

Figure 1: Two-camera JetXpert for analysis of inkjet drops-in-flight and for face-plate wetting visualization

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2.1 Strobe Control GUI

The strobe is essential to the success of the system for 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 edge trigger, pulse type, pulse width, delay times, 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.

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

2.2 Theory of Operation

JetXpert has two modes of operation—it is most commonly run in slave mode where it is triggered by an external signal from a print head driver or signal generator. There is an active mode where it is triggered by an internal clock.

In each case the strobe timing is determined based on settings in the GUI (pulse type, pulse width and delay settings).

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.

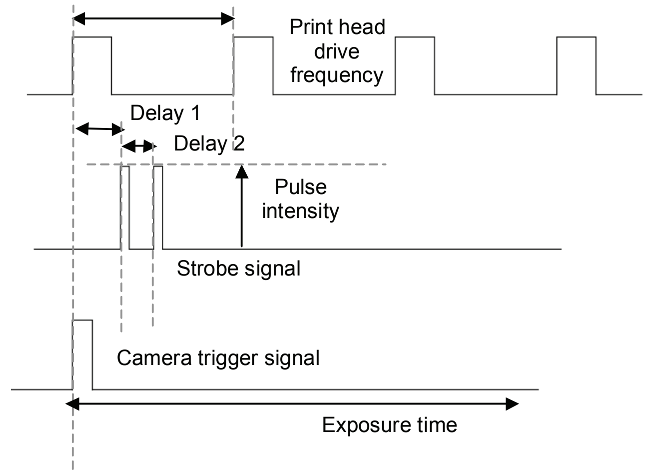


Figure 3: Conceptual sketch of a double drop (two strobes, two delays) signal relationship between print head firing frequency, the camera, and the strobe, assuming a rising edge trigger.

2.3 Shutter Speed and Droplet Aggregation

JetXpert uses one single strobe 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 that can cause blurring of the droplet image as shown in Figure 4.

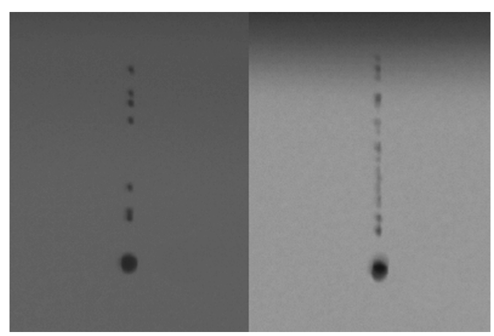


Figure 4: Single event image of droplet (left) versus 4 drop aggregated droplet image (right). Both images were taken with a strobe pulse width of 500ns. Images from Kodak print head, #10 cartridge.

2.4 Pulse Width

Changing the strobe pulse width also has an impact on image blur. This is 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 Figure 5.

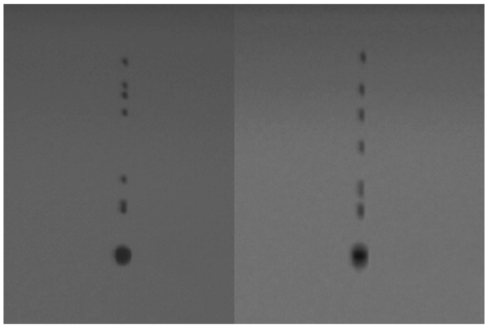


Figure 5: Single event image of droplet imaged with a pulse width of 500ns (left) versus single event image of droplet with a strobe pulse width of 1500ns (right). Images from Kodak print head, #10 cartridge.

3 MEASUREMENT METHODS

In the JetXpert software has been set up to measure several different drop attributes that are commonly of interest: velocity, volume and trajectory.

3.1 Measurement Definitions

Drop Velocity

Drop velocity is calculated by measuring the distance between the two droplets and dividing that distance by the delay time (delay2) between them plus the pulse width. It is reported in m/s.

Velocity = distance between drop 1 and drop 2 centroids / (delay2+ pulse width)

The values for Delay2 and pulse width are read automatically by the software. Velocity is reported in m/s.

The reason that velocity is not usually calculated using the position of the first drop relative to the nozzle plate is that although we know the first delay time, there is some additional unknown delay time between when a firing pulse is sent to a jet or nozzle and when the jet is actually fired or the nozzle actually ejects the droplet. This uncertainty makes the measurement of the velocity of drop 1 potentially inaccurate if only delay1 is used. If the internal delay time is known, the system can be set up to add the internal delay to delay 1 and velocity can be calculated using one drop and the distance it has traveled from the jet or nozzle.

Drop Trajectory

Drop trajectory is measured (by default) as the angle of the best-fit line through the two drops. It is relative to the image buffer, which assumes careful alignment between the ejection device and the camera. Drop trajectory is reported in degrees. In a one-camera system, trajectory can only be a projection of trajectory in the 2-D image plane. Trajectory errors in the plane orthogonal to the image plane will not be measured.

Drop Volume

Drop-based drop volume is the system default and is based on the presumption of spherical drops when drops are in free flight. The average radius of the drop is measured and the volume is calculated.

$$\text{Volume} = 4/3\pi\, r^3$$

Volume is reported in picoliters (pl).

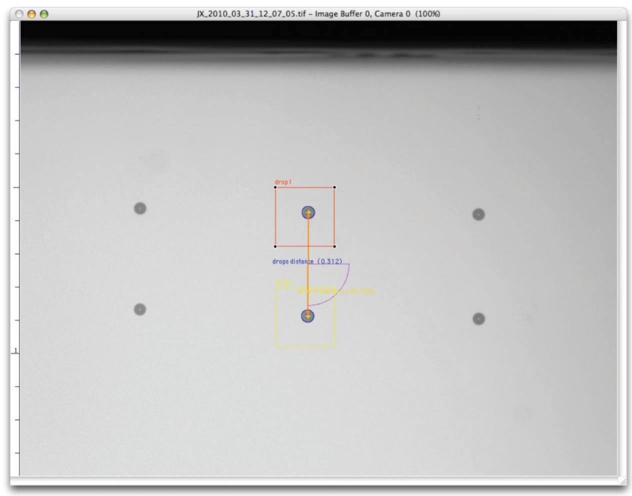
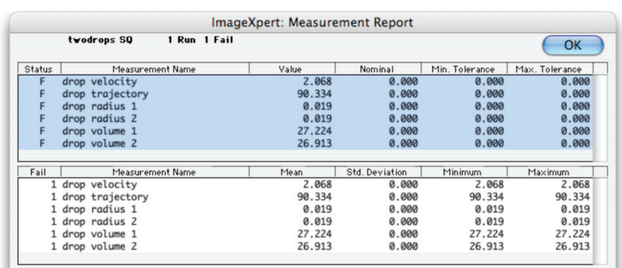


Figure 6a: Droplet volume measurement



ImageXpert: Measurement Report

twodrops SQ 1 Run 1 Fail

OK

Status	Measurement Name	Value	Nominal	Min. Tolerance	Max. Tolerance
F	drop velocity	2.068	0.000	0.000	0.000
F	drop trajectory	90.334	0.000	0.000	0.000
F	drop radius 1	0.019	0.000	0.000	0.000
F	drop radius 2	0.019	0.000	0.000	0.000
F	drop volume 1	27.224	0.000	0.000	0.000
F	drop volume 2	26.913	0.000	0.000	0.000

Fail	Measurement Name	Mean	Std. Deviation	Minimum	Maximum
1	drop velocity	2.068	0.000	2.068	2.068
1	drop trajectory	90.334	0.000	90.334	90.334
1	drop radius 1	0.019	0.000	0.019	0.019
1	drop radius 2	0.019	0.000	0.019	0.019
1	drop volume 1	27.224	0.000	27.224	27.224
1	drop volume 2	26.913	0.000	26.913	26.913

Figure 6b: Close-up view of the on-screen measurement report, showing both individual runs and accumulated statistical data

If drops are known or suspected to be more elliptical than spheroid, the software can be modified to calculate the area based on the presumption of elliptical drops ($4/3\pi$*(major axis)*(minor axis)^2).

If the volume of another object such as a ligament or series of droplets is of interest, the software can be changed to apply Ligament-based volume analysis.

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3.2 Calculation of drop volume via Ligament method

Ligament Volume

Ligament-based drop volume is calculated based on the edge points of the ligament or drop stream, as defined and bounded by a region of interest (ROI). The presumption is of rotational symmetry down the vertical axis; the volume of the ligament or droplet stream is measured based on the rotated 2-D projection.

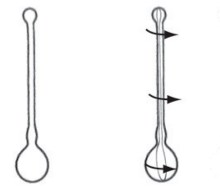

Figure 7: Ligament-based volume measurement method

The user interface allows for quick changeover from drop-based volume to ligament-based volume through a pull down menu.. Ligament based volume is most often used in dispensing applications where drops are not fully formed in flight before contacting the substrate. Volume is reported in nanoliters (nl).

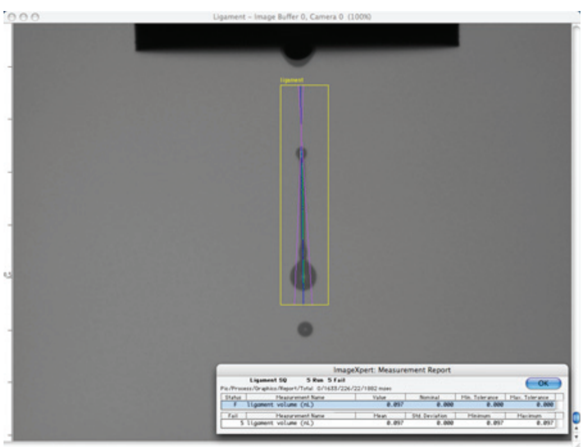

Figure 8a: Droplet volume measured including ligament

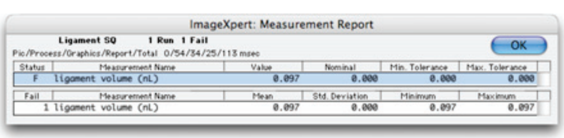

Figure 8b: Close-up view of the on-screen measurement report.

4 WETTING VISUALIZATION

The second camera allows for visualization of the face-plate in real time as the print head is being fired. The live video feed from the camera can be viewed on screen and images, image series, and movies can be captured and saved from this second camera.

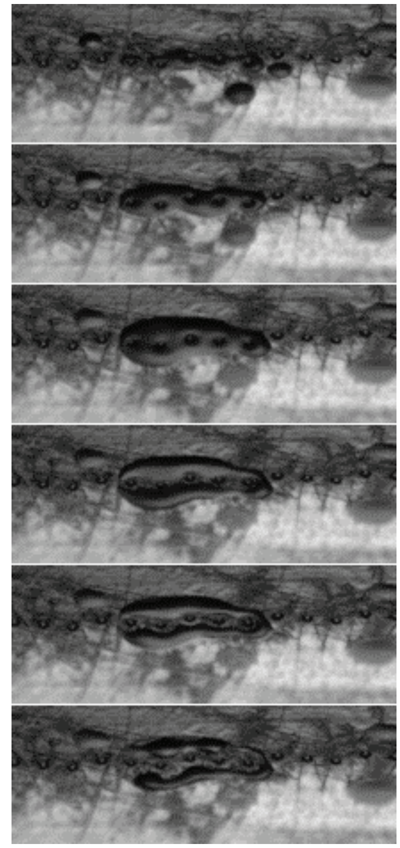

Figure 9: Image series showing wetting during firing of 5 adjacent nozzles on HP45 print head.

5 CONCLUSION

The JetXpert system can be used to analyze 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. Providing quantitative data that can be used to assess system stability and support performance verification, JetXpert can also be useful to new inkjet system development projects and for benchmarking and product comparison. It can also be of further benefit to end-users if the OEM version is integrated into final system designs for on-board process verification and control.

The second camera can be very useful for assessment of faceplate wetting during use, for both run wet and run dry systems.

REFERENCES

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