Innovative Strobe-Based Drop Analysis Equipment for Non-Contact Dispensing Systems

Y. Kipman

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

ABSTRACT

A fully integrated machine-vision based system has been developed for visualization and measurement of drops-in-flight from non-contact dispensing tips. Unlike previously offered systems in the marketplace, this system can be used with any frequency-based jetting or dispensing system that dispenses material into free flight between the dispensing head and receiving material.

An open architecture software package allows for image collection and archiving as well as powerful and flexible image analysis, including drop trajectory, velocity, radius and volume. Volume of individual droplets, or ligaments and drop streams can 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 analysis.

Keywords: inkjet, dispensing, drops in flight, drop analysis, drop visualization, drop volume

1 INTRODUCTION

Measuring the in-flight characteristics of fluid droplets under different conditions can aid in optimizing dispensing system settings, fluid formulation and system performance. Manufacturers of dispensing tips and heads, driver electronics and actuators, fluids, and integrated material deposition systems can benefit from analysis of drops-in-flight.

An integrated, machine-vision system, JetXpert, has been developed for the visualization and measurement of drops-in-flight from any frequency actuated printing or dispensing system [1]. 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 droplets.

2 SYSTEM DESCRIPTION

In the JetXpert system, the strobe is slaved to the firing frequency of the dispensing system so it can be used to measure drops-in-flight for a wide range of systems. There is also an internal clock for triggering if no external signal is available.

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 dispensing system settings and materials. In addition, the strobe control software and system allow for single event strobing, which allows for single droplets to be imaged and analyzed.

Using a digital, Firewire, black and white camera with 1024 x 768 pixels and a zoom lens, the imaging system design allows for imaging and analysis of drops down to 2 picoliters in volume.

ImageXpert image analysis software is used for droplet analysis including volume of single droplets, droplet streams, satellites and ligaments, drop trajectory and velocity, as well as other features as desired.

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. There is an option for a second camera for visualization of the nozzle or tip during operation, which can provide insight into bubble formation, build-up.

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.

2.2 Theory of Operation

JetXpert has two modes of operation—a slave mode where it is triggered by an external signal and 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 is longer than the firing frequency, there will be some 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.

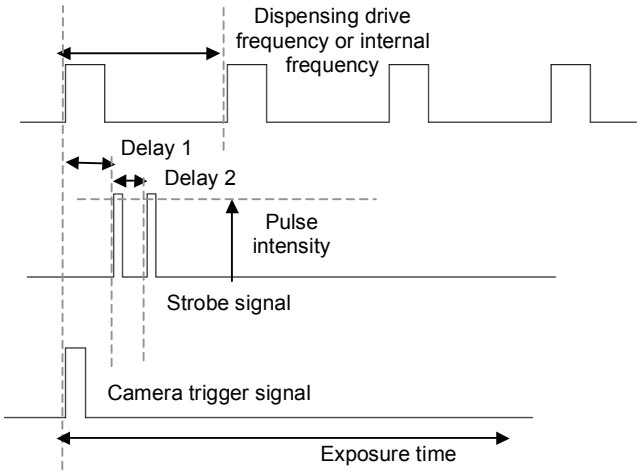


Figure 1: Conceptual sketch of a double drop (two strobes, two delays) signal relationship between dispensing head firing frequency, the camera, and the strobe, assuming a rising edge trigger.

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 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 2.

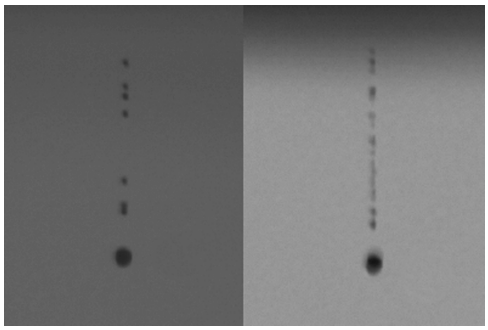


Figure 2: Single event image of droplet (left) versus 4 drop aggregated droplet image (right). Both images were taken with a strobe pulse width of 500ns. Images from Kodak print head, #10 cartridge.

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 3.

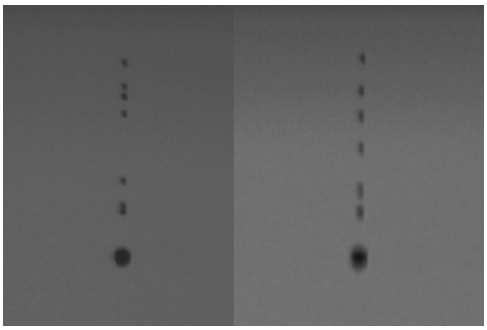


Figure 3: Single event image of droplet imaged with a pulse width of 500ns (left) versus single event image of droplet with a strobe pulse width of 1500ns (right). Images from Kodak print head, #10 cartridge.

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).

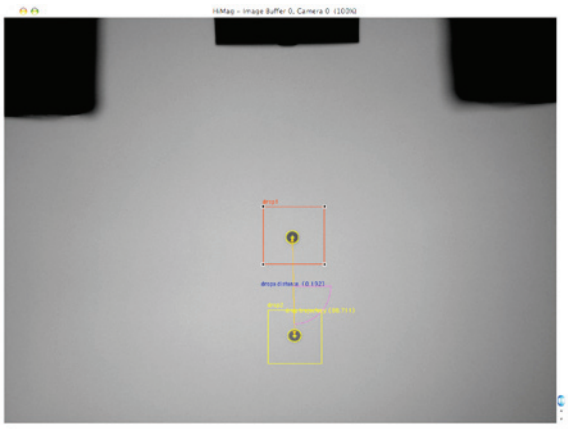
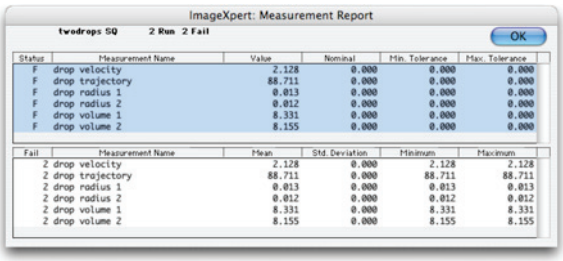


Figure 5a: Droplet volume measurement



ImageXpert: Measurement Report

twodrops SQ 2 Run 2 Fail OK

Status	Measurement Name	Value	Nominal	Min. Tolerance	Max. Tolerance
F	drop velocity	2.128	0.000	0.000	0.000
F	drop trajectory	88.711	0.000	0.000	0.000
F	drop radius 1	0.013	0.000	0.000	0.000
F	drop radius 2	0.012	0.000	0.000	0.000
F	drop volume 1	8.331	0.000	0.000	0.000
F	drop volume 2	8.155	0.000	0.000	0.000

Fail	Measurement Name	Mean	Std. Deviation	Minimum	Maximum
2	drop velocity	2.128	0.000	2.128	2.128
2	drop trajectory	88.711	0.000	88.711	88.711
2	drop radius 1	0.013	0.000	0.013	0.013
2	drop radius 2	0.012	0.000	0.012	0.012
2	drop volume 1	8.331	0.000	8.331	8.331
2	drop volume 2	8.155	0.000	8.155	8.155

Figure 5b: 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.

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.

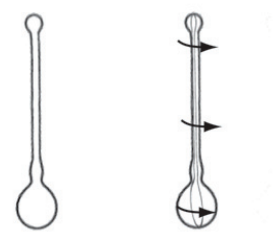


Figure 6: Ligament-based volume measurement method

The user interface allows for quick changeover from drop-based volume to ligament-based volume through a pull down menu as shown in Figure 7. 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).

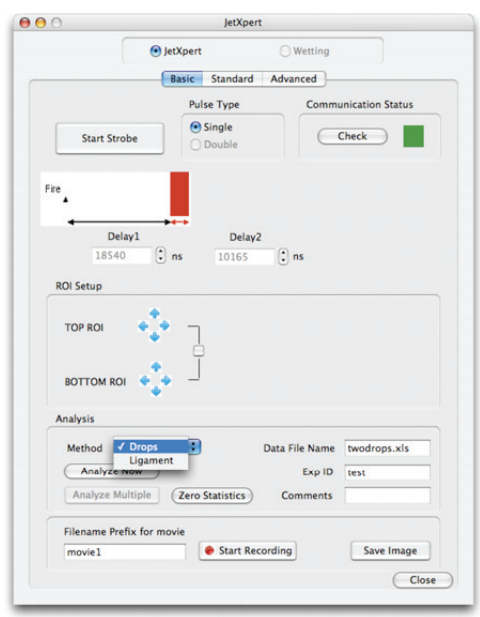


Figure 7: Strobe control user interface showing volume measurement method options

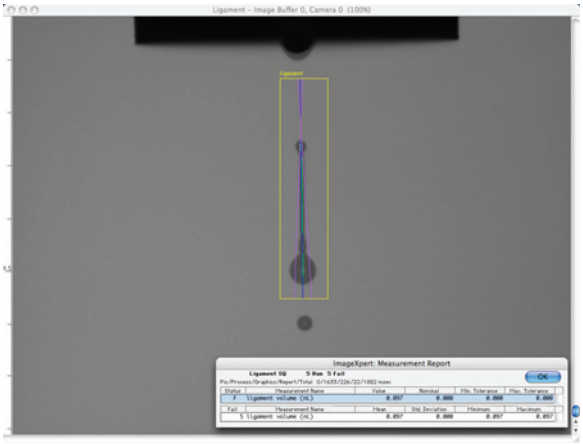


Figure 8a: Droplet volume measured including ligament

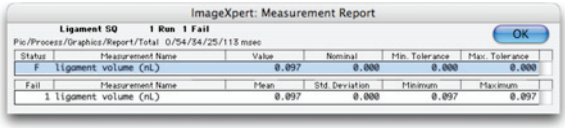


Figure 8b: Close-up view of the on-screen measurement report.

4 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 dispensing 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 dispensing 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 dispensing system designs for on-board process verification and control.

REFERENCES

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