Means For Improving Ink-Jet Printing Processes

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Abstract

Given the rapid evolution of printer technology and the ever-increasing demand for enhanced resolution, quantitative measurements of printer performances under different operating conditions are deemed necessary. The required performances could be in terms of drop sizes, optical density, color gamut and uniformity and so on. It is well known that critical issues in print quality are imperfections related to the manufacturing of print heads, the ability of the inks to form well rounded drops and the uneven spreading of ink on the print media.

More and more markets are opening towards drop on demand ink-jet printing ranging from the packaging industry to printing on electronic components. At the same time, there is need to cut down drastically the costs related to numerous and time consuming experiments with various inks on different substrates. For this purpose, we have developed an automated print quality evaluation apparatus, which allows us to follow the drop from the exit of the nozzle to drop impact. This system has a comprehensive set of built-in electronics, optical and mechanical hardware which allows taking very high magnification computer controlled photographs at different times and at different locations.

In this paper, we also focus on the design of the electronic control of jetting by means of a specific wave form generator for ink-jet print-heads. In the course of our experiments, using the aforementioned devices, we have tested the influence of the waveform and other parameters. The results provide useful metrics for analyzing relationships that exist between the initial perturbation, the drop formation and the appearance of the printed dot on some industrial materials.

Introduction

Many Print Quality Control (PQC) systems for inkjet print head are capable of identifying and rejecting heads having printing problems. The required performances[1] for the print-heads could be in terms of drop sizes, optical density, color gamut and uniformity and so on. It is well known in the existing literature that critical issues in print quality are the coalescence of ink on the print media[2,3] and/or imperfections related to the manufacturing of print heads[4]. The overall expected performance[5] is to precisely determine the relationships between ink and print head, and ink and print media. In the same time, the range of possible markets for drop on demand ink-jet printing is growing with applications in a number of areas. The fluids used are very different from a rheological point of view compared to ordinary inks. The challenge is to define a precise link between print quality and the entire drop ejection and splashing process.

For this purpose, we have developed an automated print quality optimization apparatus, which allows us to follow the drop from the exit of the nozzle to drop impact. This system has a comprehensive set of built-in electronics, optical and mechanical hardware which allows taking very high magnification computer controlled photographs at different times and at different locations, and we describe it in the first part. The second part is dedicated to the presentation of the waveform generator which helps to control the volume of the drop ejected. With this system we expect to optimize the drop ejection process as a function of the behavior of the printed material and we show some preliminary results.

Print Quality Optimization Apparatus

The commercially available PQC systems predict size and location of the dot from volume and jet angle results on each drop in flight, without directly taking into account the physical characteristics of the media, the web speed and the ink chemical composition. They might also give the two print quality metrics (size and location) from a printed test pattern, after drying and penetration effects have occurred. It is well known that, in this case, the dot size is directly linked to the media composition combined to the ink chemical behavior and this may lead to experimental artifacts when all the parameters are not considered. Certainly, the above two types of PQC systems have shown their capabilities for specific measurements, but one question remains still open. What is precisely the link between print quality and the drop formation and impact process?

To provide an answer to that question we have developed the PQOA.[6] By this method, we show that the print results obtained using various commercial print heads reveal drastic differences, which may be ascribed to ink rheology and drop formation behavior.[7,8,9,10]

In this work, we present the general design of this system. The measurements taken at each step of the drop on demand printing process will be discussed, as well as their methodology. We will dwell on accuracy, reproducibility of results, and on the automated modules of the PQOA. Figure 1 shows a global view of the PQOA fitted with one commercially available print-head.

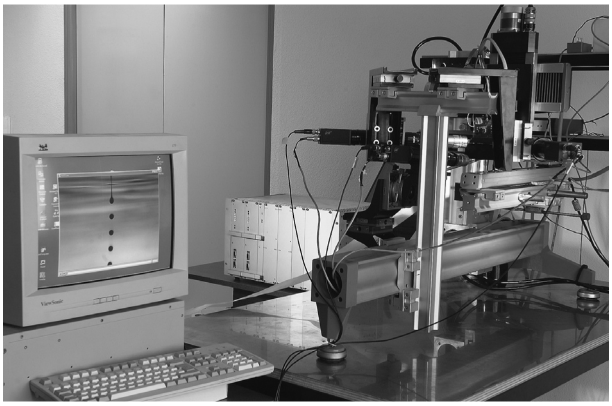

Figure 1. View of the Print Quality Optimization Apparatus

A mentioned earlier the PQOA allows the study of the drop in flight as well as the printed spot on the media. Some of the attributes of the system such as nozzle plate visualization in order to check for pollution and drop impact have required special developments both in terms of the optical and illumination systems.

Hardware Architecture

At this time, the PQOA proposes two major locations for image acquisition : nozzle plate and drop in flight. The picture represents the drop ejection process in DOD printing as seen on the video display unit When there is need to characterize the flight of the drop, two CCD (Charged Coupled Device) are used with a specific software.

To perform a control of the entire head, the first requirement is to precisely move the print head from one nozzle to another in front of the static image acquisition system. This requires a very high precision mechanical support for the head. Microstep motors combined with encoders have been chosen. The motion control is possible using the software.

The basic form of the PQOA's architecture is given in figure 2.

Optical System and Image Acquisition

Depending on the configuration, the PQOA uses one, two or three CCD cameras. Standard speed (25 images/sec) and enhanced speed (larger than 300 images/sec) cameras are available with a frame grabber. For the tome being only standard speed images have been examined. The frame grabber acquires images with adjustable magnification, according to the target object.

The electronic stroboscopic illumination control includes two types of illumination sources, laser diode and high luminosity LED. The laser diode allows longer distance of work between the object and the illumination source, and furthermore, for shadowgraphy images a higher power diffused light. Our electronic device allows us to deliver regularly spaced flashes of 100 ns. The apparatus is also capable of providing pseudo-cinematographic movies of the entire drop formation. This is specially useful for rheological and instability studies.[8-11]

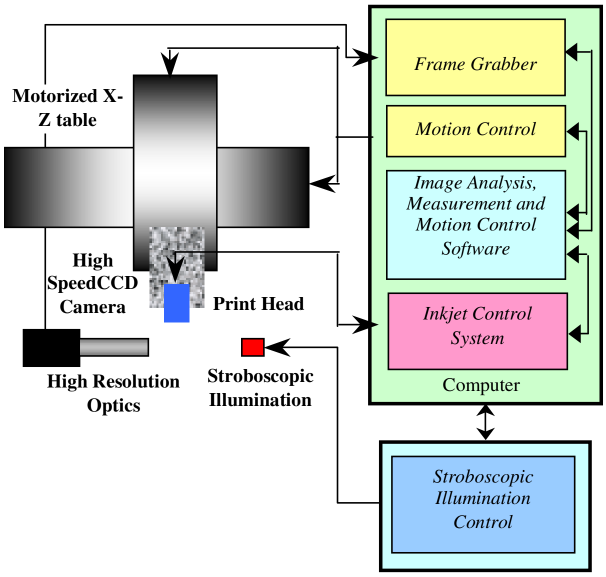

Figure 2. Print Quality Optimization Apparatus Hardware Architecture

Measurements

The system proposes several possible measurements, some of which are automated whilst other still require manual handling. In table 1, we show the main experiments which can be performed at the nozzle plate, on the flying drop and on impact. Those in italic characters are entirely automated, the others are under development

Table 1. Possible Measurements with the PQOA

Location	Measurements
Nozzle plate	• *Distance between nozzle to nozzle* • *Nozzle diameter* • Nozzle plate pollution • Nozzle Erosion
Flying Drop	• Volume • Average Speed • *Jet Angle Measurement* • Speed, Volume, Physical characteristics for filament • Speed, Volume, Physical characteristics for a possible satellite • Follow-up of Drop formation
Impact	• Impact classification

Jetting Control

A practical problem which is not really solved in the existing works is the fabrication of the waveform which should have excellent characteristics in terms of slew rate, amplitude of the signal, dwell or holding time. The accurate control of jetting is accomplished through a proprietary waveform generator[12]. Indeed in order to improve the overall performance of a print-head for a given ink, it is useful to use elaborate driving signals which represent a real richness for DOD printing.

Waveform Generator

The design of this electronic system allows to drive some of the commercially available piezoelectric ink jet with a large spectrum in terms of signal waveforms. As we have described in figure 3, the system includes a PC running under Windows tm environment, a specific power supply, an electronic rack and the analog outputs for the print-head. The power supply delivers two voltages, +240V DC and –50V DC for a positive shape, +50V DC and –200V DC for a negative one.

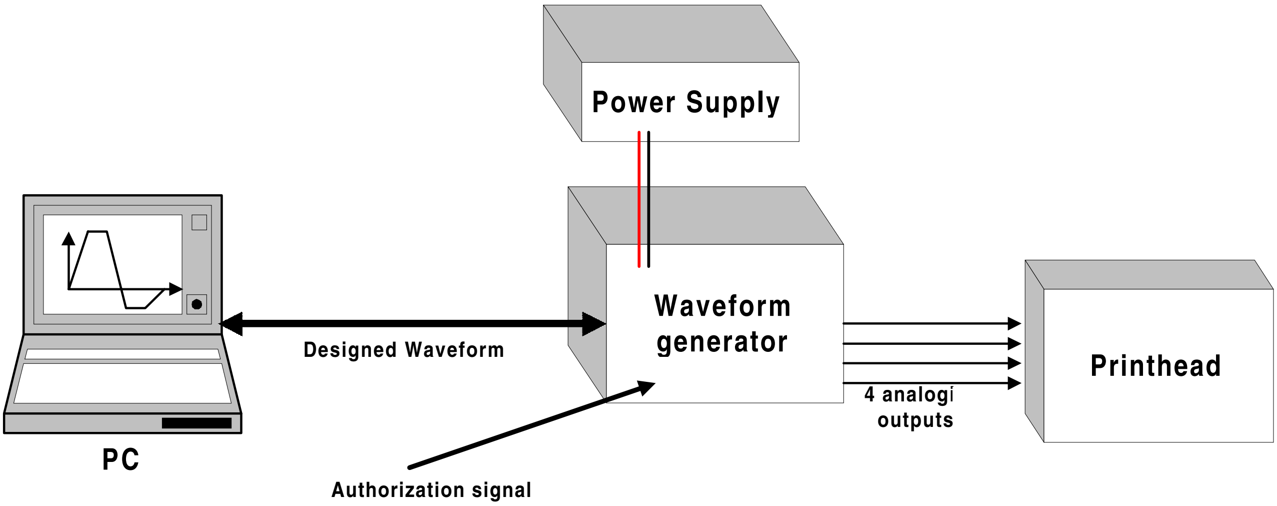

Figure 3. Principle of the electronic system

This waveform generator is able to produce a signal having any shape either positive between -30V and +200V or negative between +30V and –200V. The waveform is defined by the user using a specific software.

The waveform generator includes one interface board and two control boards. The drive board allows to apply a signal defined by the user on the piezoelectric transducers. The signal is stored in the Random Access Memory (RAM) and for each authorized signal the RAM sends the data through the Digital Analog Converter (DAC). The output signal of the converter is amplified and then applied on the piezoelectric elements. The power amplifier component has to deliver an high amperage current for each piezoelectric elements (2A max). We have studied in detail the thermal dissipation of the device. In order to cool sufficiently the rack, heat sinks and a sophisticated ventilation system are used. With this waveform generator, we have performed some preliminary tests and we give hereinafter the results. These are to be compared with results on drop size modulation in office printers which have been reported very recently.[13,14]

Influence of Pulling Voltage Upstream the Drop Ejection Signal

In this case study, we have input a negative voltage upstream the drop ejection signal in order to test the influence on drop formation. We have noted that a short negative voltage is sufficient to give additional momentum to the piezoelectric element and thus to increase the overall velocity of the ejected drop.

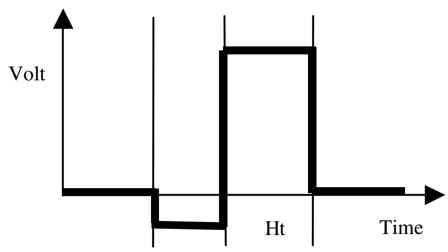

Figure 4. Driving signal for pulling voltage

Influence of Pushing Voltage Downstream the Drop Ejection Signal

This case study considers negative voltage downstream the main signal. One can note (figure 6) that this has a considerable influence on the length of the filament as shown below. This type of waveform should prove to be extremely useful in the case of viscoelastic fluids which are known to lead to long filaments.[6]

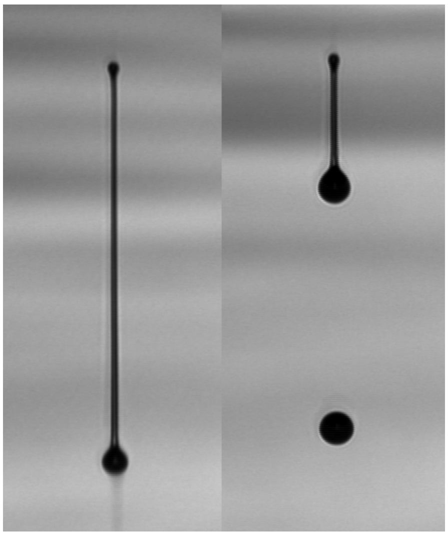

Figure 5. Influence of negative voltage on drop formation

Sample Printing

In this section, we present results on floor coverings performed with a thermoplastic ink. We have at our disposal, on one side, the print quality optimization apparatus (PQOA) which helps to visualize both the drop ejection process as well as the printed pattern. On the other side, we have the possibility to influence significantly the drop formation thanks to the waveform generator as shown in the previous section.

Standard Printing

The pattern shown in figure 6 represents conventional printing on a non-optimized substrate. As seen on the figure there is a large variation in the size of the printed dots. The smallest diameter is around 10 µm and the largest one is close to 110 µm. The small dots are either due to satellites formed with the filaments or from splashing on the substrate.

The satellites form because the filament is too long and it is subjected to Rayleigh instabilities[11] which tend to break the filament into several drops. We print with a given head and the ink has been especially formulated for the substrate so we do not want to change it. The only possibility left is to play with the waveform in order to reduce or even suppress the formation of unwanted drops.

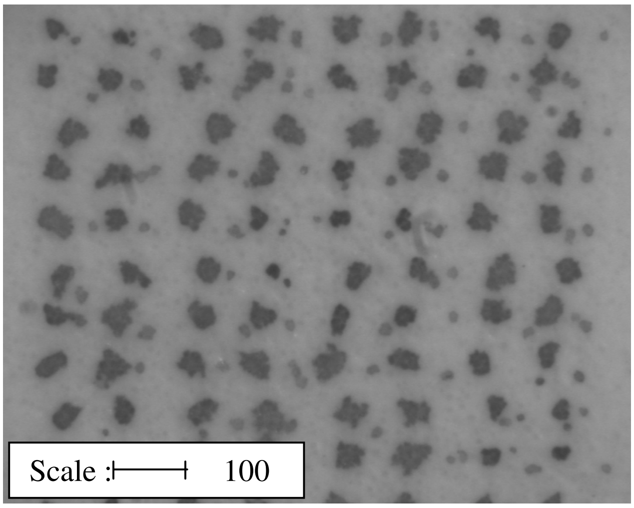

Figure 6. Standard printing on floor covering

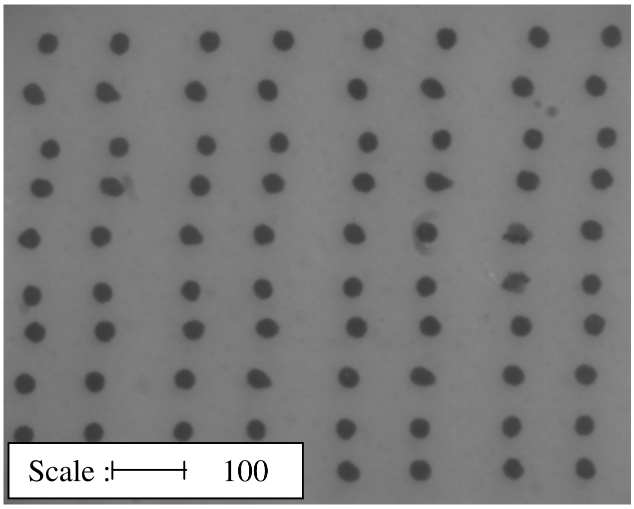

Figure 7. Optimized printing on floor covering

We have found that by reducing the velocity of the ejected drop it was possible to reduce the size of the filament and so suppress the formation of the satellite drops. This can be readily done with the waveform generator either by reducing the plateau voltage or by decreasing the holding time of the signal which is fed to the piezoelectric transducers.

Optimized Printing

The pattern shown in figure 7 represents optimized printing on the same floor covering as in figure 6 and which has been coated here with a specific varnish. As one can note on the figure the variation in dot size is much smaller compared to the previous experiment. The smallest diameter is around 45 µm and the largest one is close to 61 µm with an average size of 53 µm. The variation in size is essentially due to the fact that the drop is not completely formed at the time of impact and that part of the tail touches the substrate next to the drop.

However, the magnification of the printed pattern shows that besides the above mentioned problem which should be easily fixed, the other image quality attributes such as raggedness, satellites, geometric distortion of dots are kept well within the initial specifications.

These preliminary results on an industrial substrate show that ink-jet printing processes could be significantly improved thanks to a smart combination of physico-chemical parameters and operating conditions.

Conclusion

In this paper, we have presented specific tools for optimization of print quality and drop formation. For this purpose, we have shown that it is necessary to influence and follow the entire drop formation process, from the ejection to the impact on the media.

The measurements taken at each step of the drop on demand printing process have been presented and discussed in detail and we have pinpointed the eventual pitfalls of an analysis which is not correctly performed.

Some of the on-going work is focussed on the following items:

- Improvement of existing industrial printing systems.
- Qualification of new systems (print-head/ink/substrate).
- Drastic decrease of the costs related to numerous and time consuming experiments.

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Biography

Pascal Pierron is project leader at Ardeje a company highly specialized in the electronic and computer architecture of non impact printing processes. He is responsible for the analysis of drop on demand printing processes. He is the co-author of several papers in the field of ink-jet printing. E-mail: pierron@ardeje.com