Measuring dynamic interactions between paper and microscale ink drops

Jali Heilmann
VTT Information Technology
Espoo, Finland

Abstract

The size of a single drop determines the smallest detail that can be produced in an ink jet system. Drops of as small as three picoliters can be controllably created at the present level of ink jet technology. The final dot quality of a drop can be easily measured by an image analysis system, but the significance of high speed dynamic interactions between paper and ink cannot be determined from the final print quality. Therefore, VTT Information technology has developed several high-speed camera based systems for ink jet paper research.

This paper details a new laboratory-scale test environment developed for the measurement of dynamic interactions between paper and ink with drops of a magnitude of under 20 microns. The equipment is based on a commercial piezo-electric desktop printer, a high-speed CCD camera, an optical fibre light source and a PC with control and analysis software. In this environment, the impact, spreading, penetration and drying of very small 3 pl ink drops on the paper samples can be observed on a time scale of milliseconds up to several minutes. This article describes the development and properties of this new environment. In addition, examples of the results produced by this new equipment are given.

Introduction

Drop size clearly has a strong bearing on final print quality, because it determines the smallest size of a dot. At the present level of ink jet technology, drops as small as 3 pl are commercially utilised both in drop-on-demand and continuous ink jet printers, while in some printers the size of the drop can also be varied. A better knowledge of the basic mechanisms of the dynamic interaction between a single drop and paper is needed to produce more reliable and appropriate quality specifications for paper grades. Therefore, VTT Information technology has developed several high-speed camera based systems for ink jet paper research and has carried out several studies /1, 2, 3, 4/ to clarify the paper properties that are important in ink jet printing and to assess their significance.

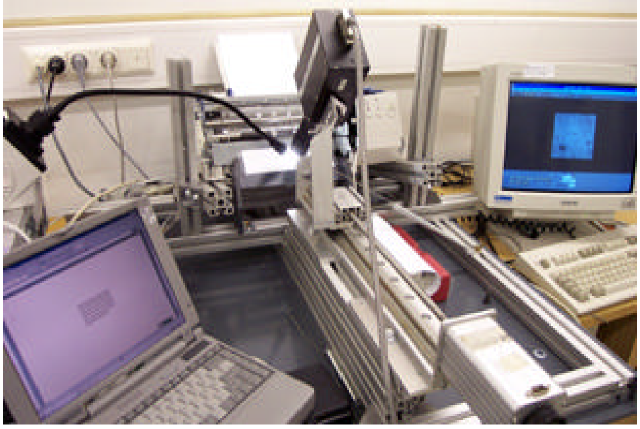
The first laboratory-scale testing environment was based on a high-speed CCD camera (2250 frames/sec), a stroboscopic flashlight and a PC. The high-speed digital CCD camera system allows the storage of a large number of digitised images (4000 frames) in the system memory (RAM), their viewing on the monitor of the PC and saving on a hard disk for subsequent image analysis. In addition, the system supports external triggering and has an output for control of the stroboscopic flashlight. A motor-driven balanced drum was set up to move the substrate. The peripheral velocity of the paper-carrying cylinder can be adjusted between 0-8 m/s. The ink drops were generated by industrial multi-deflection continuous ink jet devices. The exit velocity of the drops could be varied from 15 to 20 m/s and the size of the drops could be varied from 100 to 180 microns.

Although this environment proved to be an excellent tool for the development of ink jet papers, the experimental arrangement was more suitable for the research of high-speed ink jet printing methods. The drop size was also considerably bigger than that used in commercial low-end ink jet printing. Our ultimate goal was to develop a research method which could easily detect drops with a diameter smaller than 10 microns. This paper describes the development of this method and the properties of this new environment. Examples of the results produced by this new equipment are given.

Research Environment

The lens

While the field of view of the previous research environment was 2 times 2 mm, this time we wanted to have an area of 0.4 times 0.4 mm. It was assumed that a tailor-made lens would be needed to achieve this magnification with acceptable light intensity. Surprisingly, it was found that this magnification could be achieved by a combination of a commercial lens and teleconverter. The only downside of this lens system was that special illumination conditions had to be designed, because the light intensity of the stroboscopic flashlight of the high-speed camera was not high enough.



Picture 1. The first prototype of the micro-scale, high-speed research environment.

The light source

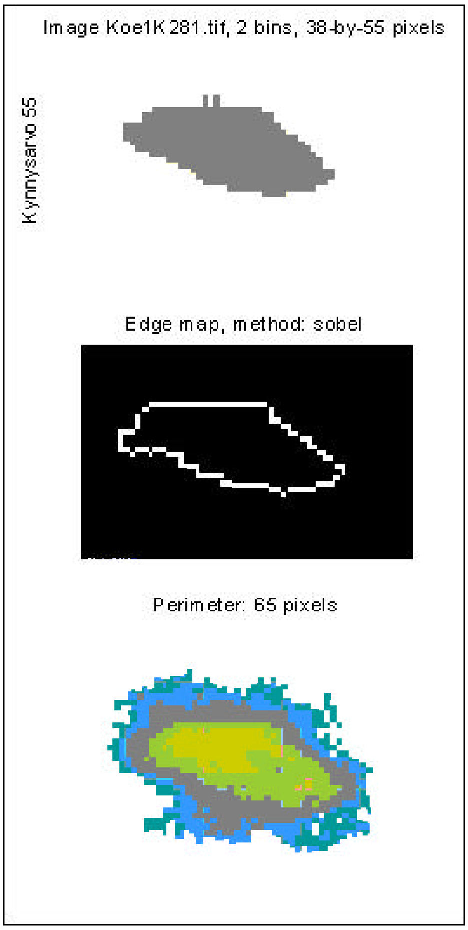
A high speed flashlight was needed to capture the drops in images taken during the flying and hitting phases in the first research system, because of the high speed of the drops in continuous ink jet printing. However, it was noticed in our preliminary test series that the shutter speed of the camera was fast enough to capture the flying drops when slower, drop-on-demand printers were used. This meant that, as a constant light source could be used, the illumination arrangements were much easier than expected. Two high-power halogen light sources with optical fibres equipped with collector lenses were selected.

The high speed camera

The speed of the high speed CCD camera used in our previous research environment was found to be faster than needed for the imaging of drops generated by low-speed, drop-on-demand printers in which the drop speed was under 5 m/sec. Therefore, the imaging speed of the camera was set at a lower level of 500 frames/sec. Another benefit of this change was that, while 1.8 seconds had previously been required to take the 4000 frames of the camera’s memory at a speed of 2250 frames/sec, now 8 seconds were required to take the same number of frames at a speed of 500 frames/sec. This was a great benefit as the lower hitting speed of the drop and the bigger viscosity of the DOD inks make the dynamic interaction phenomena between the paper and the inks slower than in high speed continuous ink jet printing.

The image analysis system

New analysis software was developed for the analysis of image data. This software converts the file format of a high-speed camera to TIF files. After that, interactive software makes it possible to zoom and select the area of interest, to choose the number of grey levels and, for the geometrical analysis, to select the threshold level as shown in Picture 2. The system produces graphs of results after the image analysis and stores the results in tables. A complete image analysis of several thousand frames can be carried out in minutes.



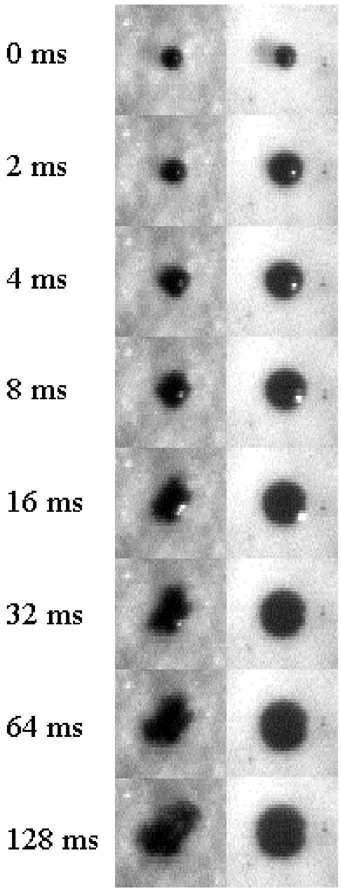
Picture 2. The analysis of a three-picoliter drop dot. Different thresholding methods and filters can be used in the image analysis software.

The printer

Due to the modular structure, different kinds of printers can be used in the research environment developed. This time we wanted to utilise as small a drop as possible to test the ultimate performance of our research system. Therefore, a commercial pietzo-electric printer, with a smallest drop size of 3 pl, was selected. The first prototype of the new research environment is shown in Picture 1.

Experimental Work

Some examples of the significance of fast absorption and the development of the technical properties of the image as a function of time were produced by using this new equipment. Only the smallest 3 pl drops were used in these comparisons, although a wide size distribution of drops can be generated by changing the printer settings. Two commercial paper grades were used in this test series. The behaviour of the 3 pl ink drops on Papers 1 and 2 during the first 120 ms after the impact can be seen in Picture 3.



Picture 3. The behaviour of 3 pl ink drops on Paper 1 and Paper 2 during the first 120 ms after impact.

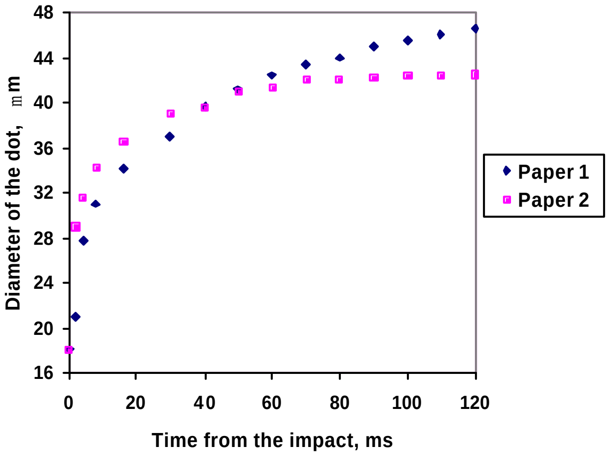


Figure 1. The diameter of the dot as a function of time.

The diameter of the dot within the first 120 ms is shown in Figure 1. After the impact, the drop immediately begins to spread on both paper grades. The grades doubled the original size of the dot within the first 30 ms. The two papers already show a difference of 5 microns in the diameter of the dot within 120 ms of impact. The shape of the spreading curves is also quite different.

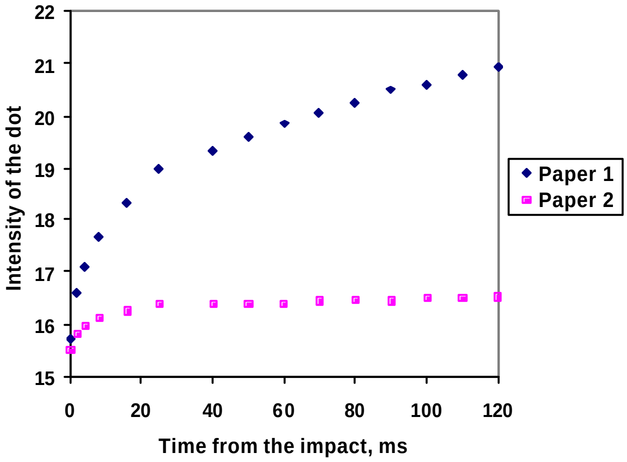


Figure 2. The intensity of the dot as a function of time.

The intensity values of the samples within the first 120 ms are shown in Figure 2. The intensity value indicates the darkness of the print: the lower the value is, the darker the print will be. Immediately after impact, the intensity of the dots starts to increase. However, the growth is much faster in Paper 1, indicating that ink penetrates faster into this paper grade, thus reducing the darkness of the dot.

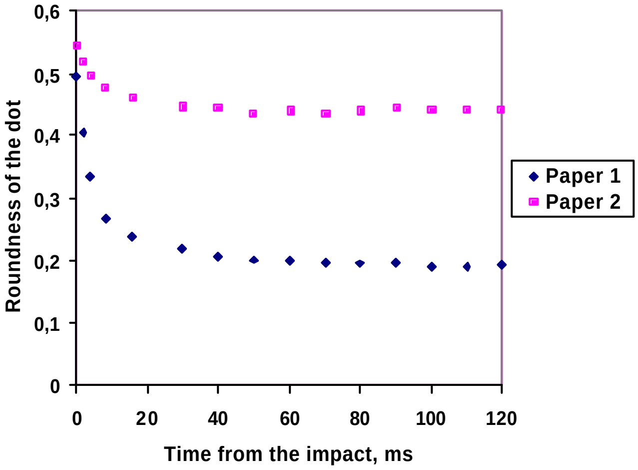


Figure 3. The roundness of the dot as a function of time.

The roundness of the dots within the first 120 ms is shown in Figure 3. The roundness values range from 0 to 1, with 1 being a perfect circle. The roundness decreases rapidly on Paper 1 within the first 120 ms. Much rounder dots can be achieved on Paper 2.

Conclusion

A novel research environment was developed for the imaging and analysis of high-speed dynamic interaction phenomena between a microscale ink drop and different paper grades. The absorption and the development of the technical properties of the image of two commercial paper grades were examined in this environment. The size of the dot was found to grow extremely fast, because both grades doubled the size of the dot within the first 30 ms. The growth in intensity, as well as the decrease in roundness, was found to be much faster on Paper 1.

All-in-all, the changes in the technical properties of the image were found to be extremely fast. There was also a clear difference between the paper grades, arising from their different properties. In the absence of any other method to detect these high-speed phenomena, our research environment has proven to be a strong and precise tool for the development of ink jet paper grades.

References

1. Heilmann, J., Lindqvist, U., Effect of Drop Size on Print Quality in Continuous Ink Jet Printing. The Journal of Imaging Science and Technology. November/December 2000. Volume 44, Number 6. pp. 491-494.

2. Heilmann, J., Lindqvist, U., Significance of Paper Properties on Print Quality in CIJ Printing. The Journal of Imaging Science and Technology. November/December 2000. Volume 44, Number 6. pp. 495-499.

3. Lindqvist, U., Heilmann, J., The Paper Dependence of the Print Quality in Drop-on-Demand Ink Jet Printing. 26th IARIGAI. Munich, Germany, 5-8 Sept. 1999. 10 p.

4. Mähönen, A., Kuusisto, M., Lindqvist, U., Nyrhilä, R., The Splashing of Ink Drops in CIJ Printing. IS&T 13th International Conference on Digital Printing Technologies. Seattle, USA, 2-7 Nov. 1997. pp. 600-603

Biography

Jali Heilmann is a research scientist with Media at VTT Information Technology (VTT stands for the Technical Research Centre of Finland). In his Master of Science thesis, he developed new electrophotography research methods. After graduating in 1995, he worked at the Media Laboratory of Helsinki University of Technology on projects dealing with colour electrophotography. He has worked at VTT since 1997. His present focus is digital printing technologies, the technical solutions, uses and appliances for electronic book technology, other new information carriers and electronic publishing. The author's e-mail address is Jali.Heilmann@vtt.fi