High Definition Ink-Jet Printing: 10-20μm Dots Eject from an Injection Needle

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Abstract

The authors developed the novel ink-jet technology using electrostatic force. One of the features of this technology is that the minute ink droplets are ejected from a large aperture. This results in fewer clogging problems than conventional ink-jet technologies. More than 2000 dpi resolution can be achieved with this technology. The dot-size can be modulated by pulse-width modulation. Furthermore, the authors observed the concentration effect of the ink when it is ejected. The essence of this technology is to eject charged ink droplets by electrostatic force. The ink contains positively or negatively charged colorants which disperse in a highly resistive solvent, and are supplied from an ink tank to the tip of an injection needle. The injection needle with an inner diameter of more than 500 μm is the ink-jet electrode. When the signal and bias voltage with the same polarity as that of the colorants is applied to the injection needle, a small meniscus is formed at the tip position. And the charged ink droplets are ejected onto the paper by the electrostatic force between the injection needle and the recording media (paper).

In this paper the features of the novel ink-jet technology, experimental setup, observation results, and the printing samples are described.

Introduction

The explosion of Internet technology is rapidly changing our life style. We can access and obtain almost any kind of information we need with high quality color images. And the performance of the digital cameras has also been improving rapidly, while the cost has become lower. Even a digital camera with mega-pixel resolution is available for less than 100,000 Japanese Yen. We can easily input full color images to a personal computer as high quality digital data, process these data, transmit them, and enjoy them on the display. The advance of these technologies has introduced a flood of color images into our information circumstances, and has increased the demand for a full color printing engine with photographic quality. On the other hand the technical progress of the copying machine causes security problems. One technology to prevent counterfeiting problems is to print characters and images with high definition dots which can not be resolved by the conventional scanner equipment. The authors believe that this novel ink-jet technology can satisfy both these demands.

Outline and Features

The principal points of this ink-jet process are as follows.

- Electrostatic force is applied to an ink.
- The ink contains a charged coloring material which is dispersed in a highly resistive solvent.
- The polarities of the coloring material and the supplied voltage to the electrodes are the same.
- The electrodes are tapered at the tip portion.

The resistivity of the ink was more than 1.0×10^{8} Ω cm. And the injection needle with an inner diameter of about 650 μm was used as the ink-jet electrode. When the signal and bias voltage with the same polarity as that of the colorants was supplied to the injection needle, a small meniscus was formed at the tip position, and the charged ink droplets were ejected onto the paper by the electrostatic force between the injection needle and the recording medium (paper).

This ink-jet technology has following features.

- Small ink droplets are ejected from a large diameter aperture
- High definition printing : 10-20 μm dots on the paper
- Less clogging problems : line head possibility
- Dot size modulation by pulse width modulation
- Recording frequency is more than 5 kHz
- Concentration effect of the charged colorants
- Supplied voltage is high : more than 1 kV
- Relatively small gap length between the electrode and a paper

The tapered shape of the electrode focuses the electrostatic force on the tip portion and makes it easy to form a small meniscus around the tapered tip shape. Then small ink droplets can be ejected from the large aperture of the injection needle, and a printing frequency of more than 5 kHz can be achieved. This ink-jet technology does not need small orifices to eject small ink droplets, so clogging problems at the orifices can be reduced. Different dot sizes can be also printed using pulse width modulation of the supplied signal voltage. When the bias voltage is supplied to the injection needle, the charged colorants with the same polarity as that of the supplied voltage move toward the stable position and concentrate at the tip portion of the electrode. Finally, high density ink droplets are ejected by adding the signal voltage. But it requires relatively high voltage and small gap length between the electrodes and the paper to get sufficient electrostatic driving force.

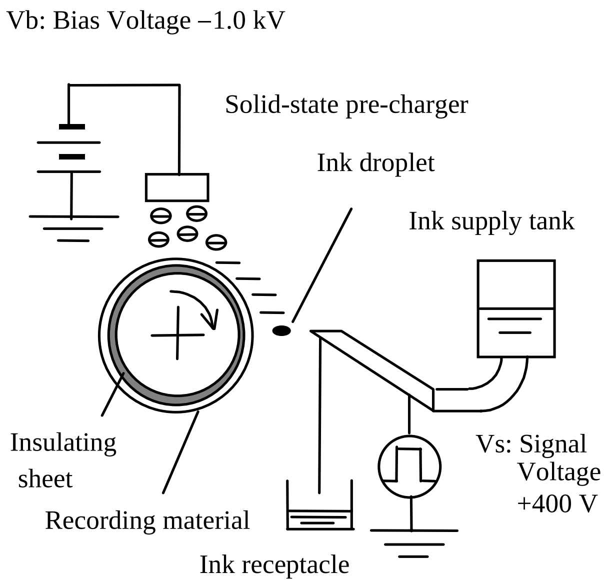

Figure 1. Schematic of the experimental setup

Experiments

Figure 1 shows the schematic of the experimental setup. The ink was supplied from the ink supply tank towards the tip portion of the injection needle through the connecting tube by gravity feed. The amount of ink flow was controlled by moving the position of the tank. The inks were black, cyan, magenta, and yellow color inks for liquid development use. The colorants were positively charged and the resistivity of the inks ranged from 5.0×10^{8} to 1.0×10^{11} Ω cm. The injection needle worked as the electrode. The inner and the outer diameters were 650 μm and 900 μm respectively. When the tip portion was too sharp, discharging occurred before the ejection of the ink droplets. So it was slightly rounded off (see Figure 2). The recording material (paper) was put on the rotating drum with an insulating sheet between. The rotating drum was attached to the X-stage which moved in the vertical direction of the rotation direction. The X-stage moved one step in one rotation of the drum, and the image was recorded on the paper two-dimensionally. The solid-state pre-charger[1] was the source for applying the bias voltage Vb to the paper. It can emit negatively or positively charged ions onto the paper to apply the surface electric potential by changing the polarity of the power supply. The signal voltage Vs was supplied directly to the injection needle according to the information to record. The driving voltage was reduced by separating the signal voltage from the bias voltage. The bias voltage and the signal voltage were −1.0 kV and +400 V respectively in the recording experiments. The positively charged ink droplets were emitted towards the paper by the electrostatic force between the electrode and the paper when the signal voltage was added to the bias voltage. The remainder of the ink overflowed from the tip portion was collected into the ink receptacle.

The following experimental results emphasize the characteristics of the novel ink-jet technology. Figure 2 shows the state of the tip portion of the injection needle when the bias voltage with different polarity (positive (A) and negative (B)) was applied to the ink containing positively charged colorants. The tip portion became clear by applying the positive bias voltage, which is the same polarity as that of the charged colorants, to the ink, and we could see the inside of the injection needle. On the other hand, the tip portion remained opaque in the case of the negative bias voltage. It means that the applied voltage affected the charged colorants and movement of the colorants occurred around the electrode.

Another feature of this ink-jet technology is the concentration effect of the ink when it flies out. When the resistivity of the ink was high and the ejection of the ink droplets was continued onto the same position of the paper, a pillar of the colorants appeared and grew at the recording position. The growth of the colorant pillar could not occur, if the ejecting ink droplets contained much solvent. It means the concentration of the colorants in the ejecting ink droplets. Figure 3 shows the growth of the colorant pillar. The size of the colorant pillar differed according to the shape of the tip portion of the injection needle, the gap length between the needle and the paper, and the applied voltage. The diameter of the pillar was about 100 μm and it took about 60 seconds to grow from Figure 3A to Figure 3C.

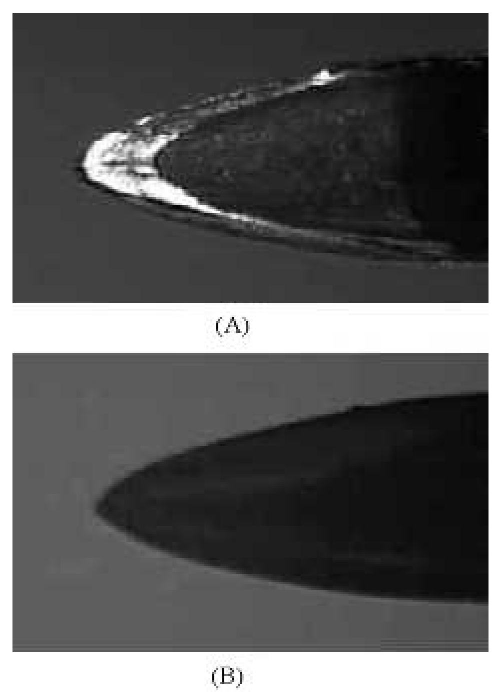

Figure 2. Different state of the tip portion with different bias voltage polarity (A: Positive, B: Negative)

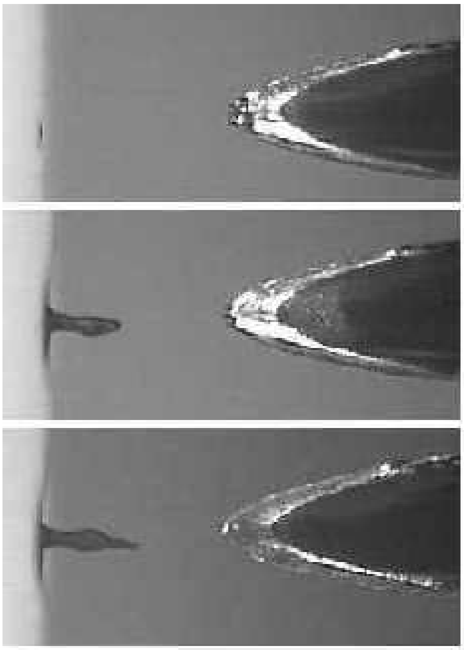

Figure 3. The growth of the colorant pillar. It took about 60 seconds from A to C.

Figure 4. Printed sample of a Japanese character pattern and micro structure letters

Printing Samples

Figure 4 shows the printed sample of a Japanese character pattern and micro structure letters. The pattern resolution was 1460 × 1460 dpi, it was arranged by the resolution of the rotary encoder attached to the rotational motor. The sizes of each Japanese character of a, b, and c were 0.5, 1.0 and 2.0 millimeter square, and each character pattern was formed by 32 × 32 dots, 64 × 64 dots and 128 × 128 dots respectively. The recording frequency was 2.0 kHz, the bias voltage was 1.0 kV, the signal voltage was 400 V, and the signal pulse width was 340 μsec in the experiment. The size of the dots was measured to be 40 ~ 50 μm. Figure 5 is the magnification of the printed letter of 0.5 millimeter square size. We can see that even such a small Japanese character pattern of 0.5 millimeter square was printed clearly on the paper.

The authors printed micro structure letters, each letter of which was formed by only 10 × 14 dots with a size of about a quarter millimeter square. The magnified micro structure letters are shown in Figure 6.

Figure 5. Japanese Character of 0.5 × 0.5 mm size

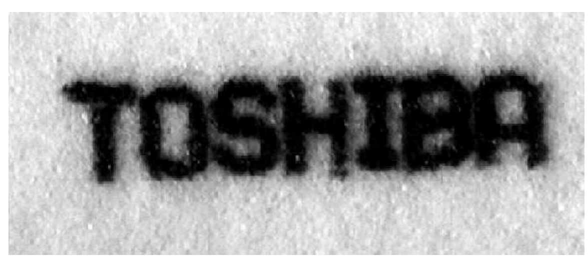

Figure 6. Micro structure letters with 10 × 14 dots and a quarter millimeter square

Figure 7 shows the dot patterns which were printed by varying the pulse width of the applied signal voltage. The recording frequency was 1 kHz to record separate dots on the paper. We can see that the dot size was changing from 20 μm to 80 μm corresponding to the applied pulse width.

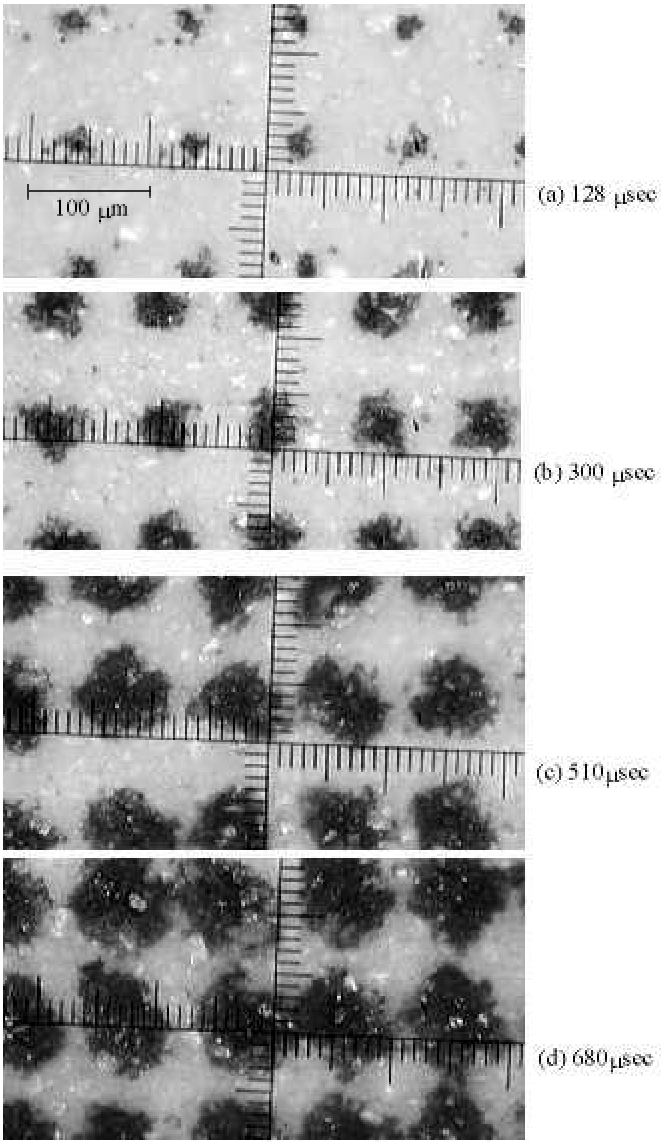

Figure 7. Dot size modulation by pulse width modulation. The recording frequency was 1 kHz.

Conclusion

The authors proposed the novel ink-jet technology with electrostatic force and presented the features of this technology. It showed some interesting phenomena such as the concentration effect of the colorants at the ejection of the ink droplet. The smallest size of the printed dots was less than 20 μm and dot size modulation was possible. The authors believe that this ink-jet technology has the potential to achieve full color printing with photographic quality and high definition, the practical line head covering the full width of the paper, and the high security-printing. The theoretical analysis of the ejecting process of the ink droplets and the development of the head device with multiple electrodes are the next stage of study for this technology.

Reference

1. Y. Hosaka, and H. Nakao, Proc. IS&T 's NIP 12 Int. Conference on Digital Printing Technologies, (Oct. 1996), p.339.