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Control and improvement of jet stability by monitoring liquid meniscus in electrospray and electrohydrodynamic jet

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ABSTRACT

Electrospray and electrohydrodynamic (EHD) jet have been paid much attention to produce fine droplets or particles. However, although applying a constant voltage, meniscus fluctuation may occur because of the variation in electric field. There are various reasons for the change in electric field such as distance between a nozzle to a substrate, wetting condition, pressure drop, and liquid vaporization. The fluctuation of the meniscus during jetting may cause unstable jetting and spray, which results in non-uniform patterning or coating. To tackle this problem, this paper introduces an advanced control of applied voltage that keeps the meniscus stable. An image processing method called meniscus characterization is used to provide information about the meniscus shape to a controller as a feedback signal. In addition, this meniscus information is also used to evaluate an optimal voltage that is applied to the nozzle to improve the startup time in the spray and EHD ejection. The experiment results show that the shape of meniscus is stably maintained, the jetting and the electrospray also become stable and the jet startup time is reduced.

1. Introduction

Since electrospray was first studied by Zeleny (1914, 1917) and theoretically explained by Taylor (1964), many researchers have investigated mechanisms that induce an electric charge on the surface of a liquid and stretch the meniscus in the direction of the electric field. When the meniscus of a liquid is subjected to a strong electric field, an electric charge is induced on the meniscus and an electrostatic force elongates the liquid to form a cone-jet (Cloupeau & Prunet-Foch, 1989, 1994; Fernández de la Mora, 1992; Gomez & Tang, 1994). Electrospray atomization of liquids in a cone-jet mode can generate nanometer-sized monodisperse droplets (Ganan-Calvo et al., 1997). Hartman et al. (1999) compared the characteristics of a spray in a cone-jet mode with a physical model. Fernandez de la Mora (1992, 1994) proposed a model of a spray in which the drops occupy a cone whose apex coincides with that of the meniscus. And recently, using the same principle, the electrohydrodynamic (EHD) jetting technology has been paid much attention due to its applications such as high resolution printing and thin film deposition. An EHD jetting device has been suggested and developed as an alternative to an inkjet device based on thermal bubbles or piezoelectric pumping (Byun et al., 2008; Choi et al., 2008; Lee et al., 2007;

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Lee et al., 2008; Nguyen & Byun, 2009; Yudistira et al., 2010). EHD printing is a technique that uses an electric field to create the fluid flows necessary for delivering inks to a substrate. This printing technique can generate a very small pattern, below 1 μm and eject high viscosity inks where the ejected droplets can carry more functional materials (Jaworek & Krupa, 1999).

There have been issues that electrospray and EHD jet printing have suffered from non-uniform film deposition or non-uniform patterning. During electrospray or the EHD jet printing process, the meniscus fluctuation may occur even with the constant applied voltage, which causes unstable jetting and non-uniform patterning or coating. This stability is a function of several parameters such as nozzle geometry, electric field strength, and flow rate. The electric field strength could be easily varied by the distance between the nozzle and the substrate. The stability could be affected by other complex phenomena of the nozzle wetting condition, pressure drop or liquid vaporization. In order to tackle this problem, an advanced control of the applied voltage could be employed to eliminate the fluctuation of meniscus. Valaskovic & Lee (2004) presented the concept of feedback control as an alternative way to the manual optimization process. However, they used the opt-electric signal for the feedback control of the applied voltage and did not show detailed implementation of the feedback control.

In the EHD jet printing, the variation of ink flow rate may cause significant effects on tiny continuous lines' uniformity. Typically for drop-on-demand printing, there have been severe technological issues on the constant volume of the liquid meniscus on the nozzle tip, the resultant uniformity of the droplets volume and the periodic ejection. In order to improve the patterning or coating uniformity, one should monitor and control the volume of the meniscus and the amount of the ejected liquid. However, until now, there has been no report to quantitatively measure the volume of the meniscus or the amount of ejected liquid to improve the stability and uniformity of the jet. Indirectly, in some applications of electrospray, the jet performance has been monitored by means of the electrical current between the nozzle and the substrate, because the current could be proportional to the amount of spraying. Mishra et al. (2010) introduced a method to ensure precision in the jetting frequency of continuous dots printing based on information from the measured electrical current. However, the electrical current could not exactly represent the amount of extracted liquid owing to a leakage current, especially when liquid is charged.

In this paper, we introduce a method for the feedback control of the applied voltage to improve the stability and uniformity of the electrospray and EHD jetting. The liquid meniscus shape is monitored during jetting by a digital camera. The control algorithm is based on the analysis of the meniscus morphology to decide the output voltage for liquid ejection. The meniscus shape is also interpreted into information about the spray and jetting status. We implement the feedback control algorithm into the EHD jet printing hardware and software, and enhance the stabilization of jetting. We also reduce the jet startup time for the first onset of jetting.

2. Experiments

Figure 1 shows the schematic diagram of the electrospray and EHD jet printing with three main modules: a jetting module, a vision module and a processing and controlling module. The jetting module includes the basic components such as a nozzle, a substrate, a reservoir and a tube. The nozzle is made of PMMA with 800 μm outer diameter and 200 μm inner diameter and connected to the positive of a high voltage supplier (Trek Inc. 10/40A), which can supply a maximum voltage of 10 kV. A counter-electrode is positioned some distance away from the nozzle and connected to the ground. The height of the ink reservoir is adjustable to control the supplied pressure by changing the difference in height between its surface and nozzle.

The vision module consists of a CCD camera (Crevis Inc.) with a micro-zoom lens and a LED backlight. It is used to capture sequential images of the meniscus. The captured images that contain information of the meniscus shape are sent to the processing module. An LED light source is located behind the nozzle to create back-illuminated images and high contrast edges of the meniscus. The shape of the meniscus is captured by the monochrome camera with a frame rate of 15 fps. The camera resolution is 2.38 μm/pixel. To capture fast movement of the meniscus, the exposure time of the camera is set to 250 μs. The processing and controlling module includes a computer, a function generator (Agilent 33220A) and a high

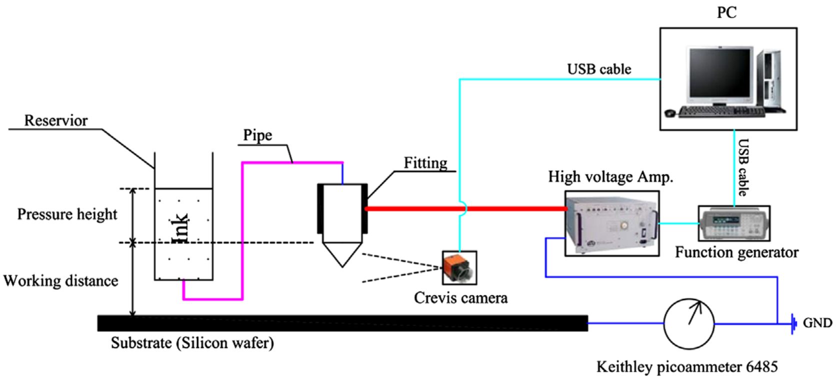

Fig. 1. Experimental setup.