Methods for Detecting Jetting Failures in Inkjet Dispensers

Kye-Si Kwon and Jung-Kook Go; Soonchunhyang University, Department of Mechanical Engineering, Chungnam, Korea
Dong-Soo Kim; Korea Institute of Machinery & Materials (KIMM), Daejeon, Korea

Abstract

Inkjet technology has recently emerged as one of the most powerful patterning tools for electronics devices. For inkjet technology to be a reliable patterning tool, the jetting status of the inkjet dispenser needs to be monitored to immediately detect any malfunction. We present a self-sensing circuit to detect failure of jetting by measuring electrical signal only. In addition, practical issues of inkjet condition monitoring for multi-nozzle printhead are discussed. Finally, software was developed and presented to demonstrate the feasibility of the proposed method for detecting jetting failures in printing systems.

Introduction

Inkjet printing uses ink droplets to form required patterns on a substrate. With inkjet technology, the volume of a droplet from the inkjet printhead can be controlled to an accuracy of picoliters and the droplet can be placed onto the substrate to an accuracy of micrometers. Due to these features, inkjet technology has recently emerged as one of the most powerful tools for patterning electronics devices, such as large area display applications, radio frequency identification (RFID), printed circuit board (PCB) [1-3].

The key inkjet printing components for printed electronics are motion stages, an inkjet printhead (dispenser), materials (ink) and substrates. The most important component to ensure the productivity and reliability may be the inkjet printhead. Any problems in printhead jetting performance must be identified and fixed immediately: therefore, studies have been performed to monitor and identify jetting conditions [4,5].

A piezo inkjet printhead uses a piezoelectric crystal. By applying a waveform voltage, the piezo can create pressure waves, which expel ink droplets. The piezo actuator in the inkjet dispenser can be used as a sensor: it senses the force that results from the pressure wave inside the dispenser. The use of a piezo as both a sensor and actuator has been tried in many other engineering applications due to its so-called self-sensing capability [6]. There are currently two inkjet applications: the design of waveforms for driving inkjet dispensers [1,7], and the detection of inkjet malfunctions [4,5]. In this work, self-sensing measurement techniques and their application to inkjet malfunction detection are proposed.

Two commercial printheads were considered in this study: a single nozzle dispenser from Microfab (MJ-AT-01-50) and a multi-nozzle printhead from FUJIFILM Dimatix (SE-128). Faulty nozzle detection schemes based on self-sensing techniques were developed for each head.

To measure a self-sensing signal for the single nozzle Microfab printhead (MJ-AT-01-50), a bride circuit was developed [5]. Driving voltage and driving current are the two major concers in measuring piezoelectric self-sensing signals. The actual driving voltage for piezo can be changed (reduced) from the original driver voltage using a sensing resistor (or capacitor) to measure the self-sensing signal. To drive both the the piezo-actuator and the equivalent capacitor, driving current can be increased. Thus, the driving current can be an issue in measuring the self-sensing signal, especially for a piezo-actuator with large capacitance.

Measuring the self-sensing signal of each ejector in a multi-nozzle printhead might require as many detecting circuits and data acquisition channels as the number of nozzles in the printhead. Therefore, a self-sensing implementation is likely to be more expensive and complicated than for a single nozzle device. On the other hand, in some commercial printhead, a multi-nozzle head may have a common ground for driving each nozzle or there may be a shared driving line for driving many nozzles at the same time. Therefore, the measurement scheme and algorithm may differ significantly according to the design of the commercial inkjet head. We used an SE-128 multi-nozzle head from Dimatix. In this design, only two drivers are needed to drive 128 ejectors. A new scheme for detecting jetting failure from the SE-128 was developed and the advantages and limitations of the proposed methods are discussed.

Jetting failure detection from a single nozzle printhead

Possible causes of inkjet malfunction include air bubbles entrapped in the dispensers, ink degradation, aging of the inkjet dispenser, an environmental change such as temperature, blockage of the nozzle due to particles and nozzle clogging due to ink drying on the nozzle surface. Among these malfunctions, air-bubbles trapped in the dispenser are a major problem that can result in jetting failure since the air bubbles can be generated even during the drop formation [4]. This work mainly discusses piezo self-sensing detection and monitoring methods for inkjet jetting failure due to air bubbles.

Piezo in the inkjet dispenser can be used as both sensor and an actuator. Therefore, it can be used as a monitoring tool during the printing process. In piezo current, there are two components when waveform voltage V is applied to the piezo: a self-sensing signal, i_q , and a powering signal, i_c , as follows [1]:

$$i = i_q + i_c \qquad (1)$$

where $i_c = C\dfrac{dV}{dt}$ and $i_q = \dfrac{dq_p}{dt}$.

Here, i_q comes from the piezoelectric charge due to the change of the piezo-strain whereas i_c is the powering current which comes from the applied voltage behaving like a capacitor with capacitance C. To extract the self-sensing signal, the powering signal must be removed from the measured piezo current. For this purpose, a bridge circuit, as is shown in Fig.1, was used to extract the self-sensing signal from the piezo [5].

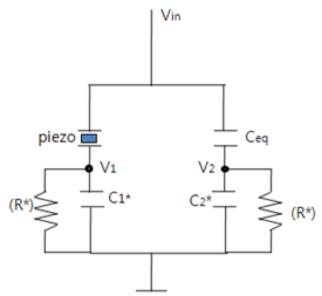

Figure 1 A bridge circuit for piezo self-sensing [5].

From the bridge circuit, a self-sensing signal was obtained through the voltage difference V_1-V_2: this signal can be implemented using differential amplifiers [5].

Software was developed to monitor droplet jetting from a CCD camera with a strobed light emitting diode (LED), as shown in Figs. 2 and 3. By using the strobe LED system, abnormal jetting behavior can be visualized. In addition, self-sensing signals were acquired for monitoring, and were compared with the signal measured during normal status. By setting the threshold value to the monitoring value, which is defined by square of difference between normal signals and monitored signals, the software algorithm can automatically determine when the abnormality occurs, and its severity.

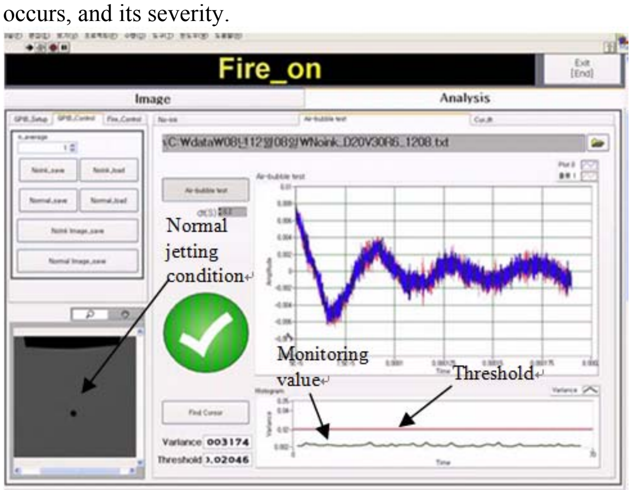

Figure 2. Software developed to monitor jetting status (normal condition) [8].

Figure 2 shows the jetting behavior image and self-sensing signal. As seen in the figure, the monitored self-sensing signal (red line) is in good agreement with the self-sensing signal saved at the normal condition (blue line). As shown in the CCD camera in Fig.3, when abnormalities occur in jetting such that the droplet jetting speed decreases (appearing as multiple droplets in the image), the monitored signals (red line) differ significantly from the normal signal saved at normal status (blue line). For more information, a video clip can be found in [8].

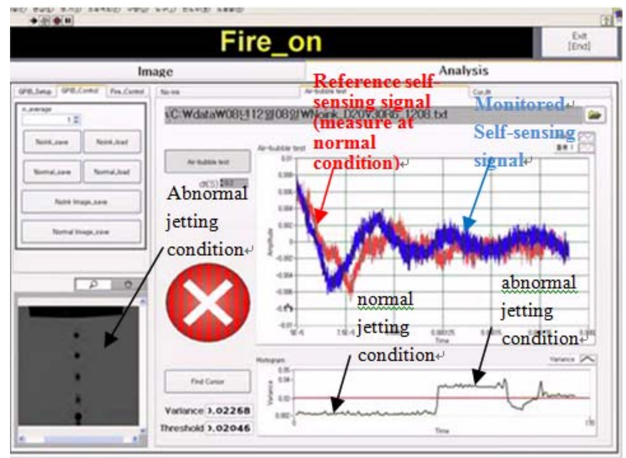

Figure 3 Software developed to monitor jetting status (abnormal condition) [8].

Jetting failure detection from multi-nozzle head

Most industrial inkjet printheads have many dispensers to increase their productivity as a manufacturing tool. As a result, there can be many wires from the printhead to the driver. To simplify wiring connections, most printheads use a shared common driving (or ground) line. Thus, the measurement of a self-sensing signal needs different schemes based on the specific inkjet head and driver electronics. In addition, there will be limitations in the case of a head with shared ground (or driving), since the measured piezo current is the sum of the current from each dispenser. For example, for a commercial multi-dispenser inkjet printhead such as SE-128 from Dimatix, only two drivers are required to drive 128 nozzles. Due to the shared ground (driving) line issue, condition monitoring may not be possible when the actual printing on a substrate is in progress. Nevertheless, condition monitoring using self-sensing can be practically implemented by one nozzle firing at a time in a sequential manner because the diagnostic process can be fast. This quick diagnosis is possible because only electrical signals are used without any precise mechanical alignment for monitoring a specific dispenser. Therefore, the diagnostic process can be performed while the printhead is moving to the next printing swath. In such a case, a low input waveform voltage can be applied for test purposes so as not to eject any droplets. Condition monitoring without droplet jetting has advantages because it can avoid contaminating the substrate by test jetting near the patterning area [5]. If air bubbles are detected from the monitoring process, then the printhead should be moved immediately to the designated place for fixing such problems by using proper maintenance schemes.

To implement a diagnostic algorithm approach based on one nozzle firing at a time, a sensing resistor (or output impedance) inserted between the driver and inkjet head was used as shown in Fig. 4, was used. The resistance can range from few ohms to dozens of ohms. Note that a sensing capacitor can be used instead of the sensing resistor and the measured voltage after the sensing resistor V_{out} differs according to jetting conditions due to the generated piezo self-sensing signals. To extract only the self-sensing signal, reference signal V_{ref} was used to drive the equivalent capacitor. The capacitor was used to remove powering signals from the piezo.

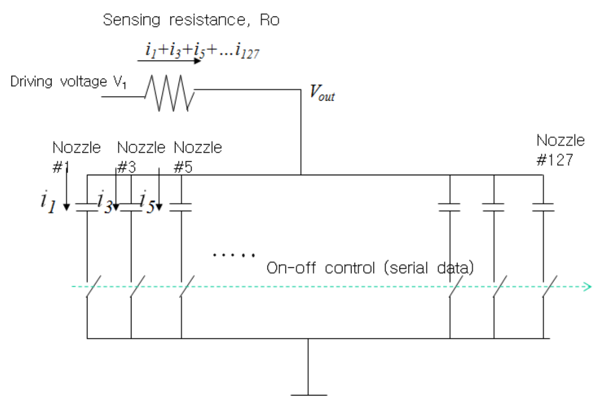

Figure 4. Piezo self-sensing signals from multi-nozzle head.

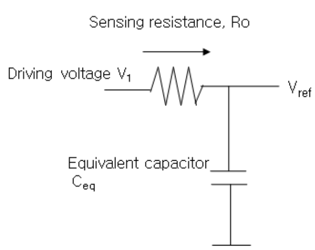

Figure 5. Reference signal to extract self-sensing signals from piezo.

As a final step, the self-sensing signal was obtained by subtracting V_{ref} from the measured V_{out} as shown in Fig. 3. The subtracted signal was filtered and amplified before the signals were acquired from the data acquisition (DAQ) system.

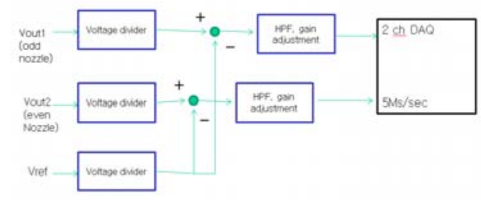

Figure 6. Extracting self-sensing signals

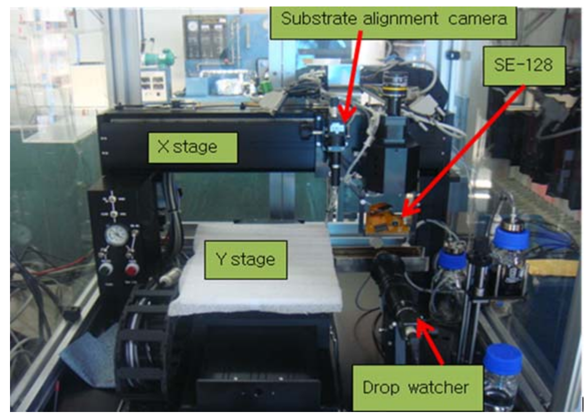

Figure 7. Experimental setup.

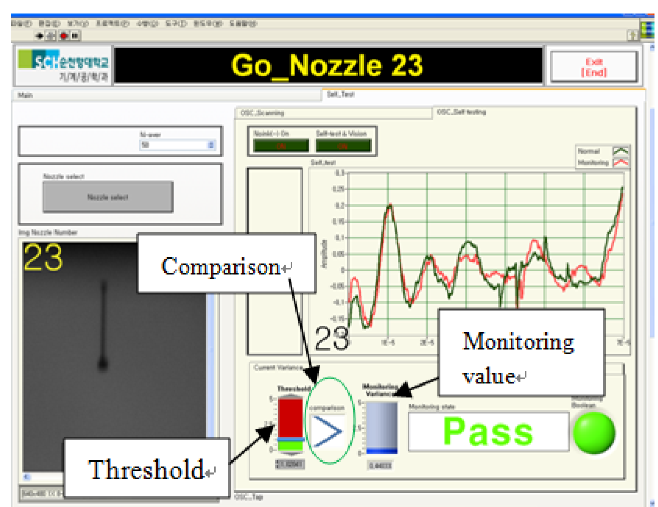

Figure 8. Software developed to detect jetting failure.

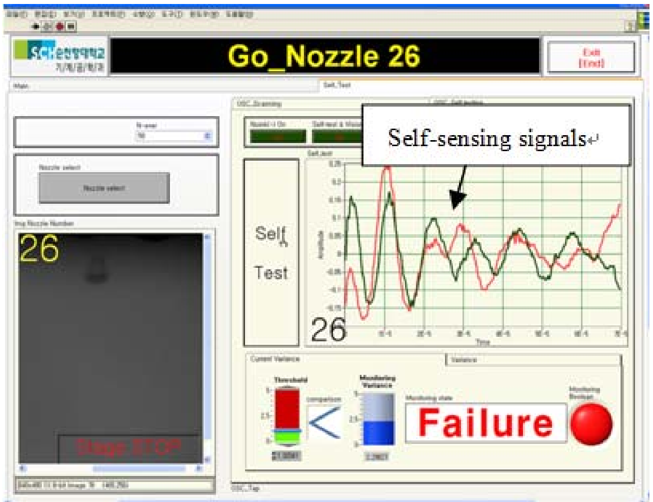

Figure 9. Software developed to detect jetting failure.

Figures 8 and 9 shows the software developed to compare droplet images and self-sensing signals. The self-sensing signals from each nozzle measured at normal jetting conditions (red line) are compared with the monitoring signals (green line) of each nozzle. Then, if the monitoring signals have deviated from the normal condition, the status is diagnosed as jetting failure. A video can be found from the website in [9]. There are challenges to overcome to use this technology commercially. The main difficulty is electrical noises since the self-sensing signals are weak in most cases. Also, there are cost issues related to measuring the self-sensing signals because an additional device is needed for monitoring and the data processing. Finally, the detection algorithms need to be improved to scan many nozzles much more quickly.

Conclusions and discussions

To monitor the operating condition of an inkjet dispenser, the self-sensing techniques were applied to inkjet printing technology. The self-sensing signal, which represents the pressure wave inside the dispenser, was measured from two commercial printheads; a single nozzle head (Microfab MJ-AT-01-50) and a multi-nozzle head (SE-128).

For the single nozzle head, it is possible to detect abnormal jetting behavior via electrical signals. Condition monitoring using the piezo self-sensing is possible during the actual printing process since it does not require any mechanical alignment with respect to the measuring device.

However, for a commercial multi-nozzle head such as the SE-128, the proposed application can be limited because condition monitoring needs to be performed by scanning one nozzle after another to determine whether or not the operating status of a nozzle is normal. This is because the SE-128 has common driving line for many nozzles (64 nozzles). Note that the measurement techniques for inkjet malfunction in multi-nozzle heads are likely to be design-dependent. Therefore, when a different head is used, different schemes must be sought. To overcome such limitations in multi-nozzle heads and to maximize piezo self-sensing ability for detecting inkjet malfunctions, the printhead manufacturer may need to design new head or driver electronics for easy and fast condition monitoring.

Acknowledgement

This study was supported by a grant from the Ministry of Knowledge Economy, Republic of Korea. The authors are grateful to Dr. Seogsoon Kim, CEO of Unijet, for useful technical discussions.

References

[1] K.S. Kwon and W. Kim, "A waveform design method for high speed inkjet printing based on self-sensing measurement," Sensors and Actuators A, 140, pg. 75. (2007).

[2] T. Gohda, et al., A 3.6-in 202-ppi Full-color AMPLED Display Fabricated by Ink-jet method, SID 2006 (2006).

[3] D. Albertalli, Gen 7 FPD Inkjet equipment-development status Proceedings of the SID 05 Digest, 2005.

[4] J. D. Jong, G. D. Bruin, H. Reinten, M. V. D. Berg, H. Wishoff, M. Versluis and D. Lohse, Air entrapment in piezo-driven inkjet printheads, Journal of Acoustical Society of America, 120(3) (2006) 1257-1265.

[5] K. S. Kwon, Methods for detecting air bubble in piezo inkjet dispensers, Sensors and actuators A, doi:10.1016/j.sna.2009.04.024.

[6] C. Lee, T. Ithoand and T. Suga, Self-excited piezoelectric PZT microcantilevers for dynamic SFM with inherent sensing and actuating capabilities, Sensor and Actuators A**,** 72 (1999) 179-188.

[7] M. B. G. Wassink, M. J. M. Bosch, O. H. Bosgra and S. Koekebakker, Enabling higher jet frequencies for an inkjet printhead using Iterative Learning Control, in: Proceedings of the 2005 IEEE conference on control applications, Toronto, Canada, 2005.

[8] K.S. Kwon, air bubble detection in piezo inkjet printhead, http://www.youtube.com/watch?v=Yp0LrS8c-tI, 2009.

[9] K.S. Kwon, Inkjet jetting failure detection, http://www.youtube.com/watch?v=0nWGGX0z0ow, 2009.

Author Biography

Kye-Si Kwon has been an assistant professor at Soonchunhyang University in Korea in the department of mechanical engineering since 2006. He received his BS degree in mechanical engineering from Yonsei University, Seoul, Korea in 1992. He holds a master's degree (1994) and a PhD (1999), both in mechanical engineering from KAIST, Korea. Before joining Soonchunyang University, he was a member of the research staff at the Samsung Advanced Institute of Technology. His current work is focused on the development of measurement methods for controlling inkjet head.

Jung-Kook Go has been a candidate for the M.S. degree at Soonchunhyang University since 2009.

Dong-Soo Kim received his M.S. and Ph.D. degrees in Mechanical Engineering from Yung Nam University, Korea, in 1991 and 2001, respectively. Dr. Kim is currently the general manager at Nano Mechanical System Research Division at Korea Institute of Machinery & Materials. His research interests include Printed Electronics, R2R, ESD, Inkjet Printing, RP system.