Development of Inkjet Monitoring System via Piezo Self-Sensing

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Abstract

Inkjet technology has recently emerged as one of the most powerful patterning tools for electronic devices. 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 low cost and high speed monitoring module to monitor the jetting condition of a piezo-driven multi-nozzle inkjet head. The developed self-sensing method can detect non-jetting conditions as well as poor jetting conditions such as jetting speed reduction and poor jet strightness. We are testing the long term reliability of the proposed monitoring techniques by comparing the self-sensing signal and vision droplet image.

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 electronic devices, such as large area display applications, radio frequency identification (RFID) devices, printed circuit boards (PCBs) [1, 2].

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 is 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.

A piezo inkjet printhead uses a piezoelectric crystal actuator. By applying a voltage waveform, the piezo actuator can create pressure waves that expel ink droplets. A piezo actuator in the inkjet dispenser can also be used as a sensor that senses the force resulting 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. There are currently two inkjet applications: the design of waveforms to drive inkjet dispensers [3,4], and the detection of inkjet malfunctions [5-7].

In this study, we examined self-sensing monitoring techniques to detect inkjet malfunctions. The feasibility of using piezo self-sensing signals to detect inkjet jetting failures has been discussed in literatures [3-6]. However, few published studies have dealt with practical problems such as monitoring speeds and software algorithms. These practical issues are becoming important for the technology to be used in inkjet based manufacturing system. Recently, a method for monitoring a multi-nozzle head was presented by the author [7]. However, the measurement scheme and algorithm in [7] were not optimized. As a result, the monitoring speed was too slow to be used in practice.

In this study, to overcome previous shortcomings, we developed a high speed monitoring module that can be easily integrated into an existing printhead. The hardware of the monitoring module was simplified such that only one analog input channel from the data acquisition (DAQ) system is required to monitor 128 nozzles. Also, the scanning time for data acquisition of all nozzles was minimized by scenario-based jetting and measurement. Finally, we developed software program that allow the nozzle status of a multi-nozzle head to be understood at a glance. In the developed software, we compared the monitoring results with vision-based measurements for the verification. As a reliability test, we developed a software algorithm that can save images and self-sensing data during long term jetting conditions. By comparing the self-sensing signal and vision image, the monitoring results based on the self-sensing signals were verified.

Low Cost Monitoring Module Development

To demonstrate the proposed method, a commercial multi-nozzle inkjet printhead (SL-128, Dimatix, USA) was used in our study. The printhead uses two shared drivers for 128 nozzles: one driver is used to drive odd-numbered nozzles, and the other driver is used to drive even-numbered nozzles.

To obtain the piezo self-sensing signals, electronic circuits to measure piezo current should be inserted between the drive and inkjet head. Also, a bridge circuit needs to be modified to use the shared driving line to measure current and extract the self-sensing signal from the SL-128. For this purpose, we developed a monitoring module as shown in Fig. 1. In this module, the measuring circuit and hardware were optimized such that only a single circuit and DAQ channel were required to monitor all of the nozzles in the SL-128. Thus, the hardware cost can be minimized. If it is mass-produced, we expect that the hardware cost will be less than $100 (U.S. dollars).

The module-based circuit hardware has advantages because it can be easily integrated into existing hardware. The developed monitoring scheme can also be extended to other multi-nozzle heads.

Figure 1. A low cost and high speed monitoring module.

The proposed method uses the current measurement at the shared line, and monitoring may not be possible during the printing mode in which more than one nozzle needs to be jetted simultaneously. Therefore, the monitoring process needs to be performed between printing swaths as shown in Fig. 2.

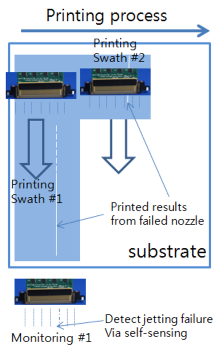

Figure 2 Monitoring scheme based on self-sensing

The monitoring process takes time, which can increase the total time for printing. Therefore, to increase manufacturing productivity, the reduction of monitoring time is one of the key technical problems to be solved. We found that the data acquisition scheme and its processing time account for the most monitoring time.

In most conventional DAQ systems, measurement is based on acquiring and processing the sensing data (or saving the data in a computer hard disk) before the next data acquisition. As a result, time, T_{daq}, was required between two acquisitions due to the re-configuration of DAQ for the next acquisition and data download. The data are downloaded to a personal computer (PC) for further data processing in a conventional DAQ system. In addition, re-configuration of a pattern generator to select a nozzle for jetting is required because the measurement scheme is based on monitoring one nozzle at a time, prior to monitoring the next nozzle. Nozzle selection for jetting requires communication between PC and the pattern generator via universal serial bus (USB) communication, and takes time $T_{pattern}$. As a result, the total time required to monitor a printhead with 128 nozzles was measured to be about 10 s using the conventional DAQ system described in [7]. The total time of 10 s for scanning a whole nozzle might not be fast enough to be used in a manufacturing system.

To reduce monitoring time, we developed a new measurement scheme to replace the conventional approaches. For this purpose, testing conditions, such as the monitoring nozzles and the averaging number for data acqusitions were set prior to monitoring process. This was done by initially uploading the jetting scenario in the pattern generator and DAQ system. As a result, there was no need for communication between the PC and pattern generator (or DAQ system) for re-configuration during the monitoring process. Using the proposed method, the jetting nozzle can be changed between consecutive trigger signals that are internally generated at a particular frequency (e.g., 5 kHz) from the pattern generator. Also, we note that the jetting scenario should be incoporated with data acquisition such that all the jetting triggers can be used for data acquisition. For this purpose, DAQ hardware was developed such that the self-sensing signals were acquired at each jetting trigger, and each acquired data item is temporally stored in the random access memory (RAM) in the DAQ system. After acquring self-sensing signals of entire nozzles based on the jetting scenario, all the data stored in the RAM were downloaded to the PC for further data processing. By developing a DAQ system based on the proposed method, the monitoring speed could be reduced signficantly, unlike conventional methods. The developed DAQ scheme was integrated into the monitoring module where the developed sensing circuit was located. The DAQ sampling rate is 1MS/s, and 1 megabyte (Mbyte) of RAM was used in the DAQ system. Configuration of the data acquisition and data transfer to the PC was accomplished via USB communication between the PC and monitoring module.

Assuming that the jetting frequency is 5 kHz and the averaging number is 10 for each nozzle, then it will take only 0.256 s to scan 128 nozzles using the proposed method. So, the scanning time for all the nozzles is fast enough to be applied during the printing process at a regular or irregular basis without major interruptions of the printing process. However, we note that it will take additional 1 or 2 s to calculate the measured signals and show the results in an effective way. This time requirement is mainly related to computer speed, and we expect much faster results in the near future as computer processing speeds and capabilities advance.

Software Development

To demonstrate the proposed method, the monitoring module was integrated into the laboratory-developed printing system shown in Fig. 3. The printing system had a drop watcher module to visualize droplet images. To observe the droplet image from a specific nozzle, linear stages were used for position control. We used a strobe LED light for drop visualization using a charge-coupled device (CCD) camera to verify the monitoring results.

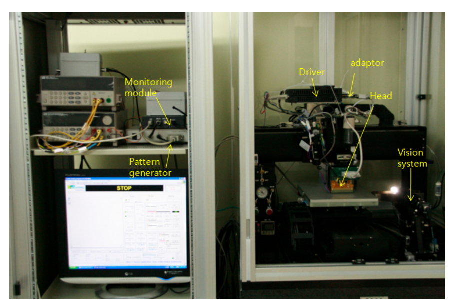

Figure 3. System integration for self-sensing monitoring [8].

Software was developed to determine the jetting status of a multi-nozzle head and show the monitoring results. The status of each nozzle can be understood at a glance. For example, Fig. 3 shows the developed software. The monitoring results indicate that there are two abnormal jetting nozzles (red-coloured indicators).

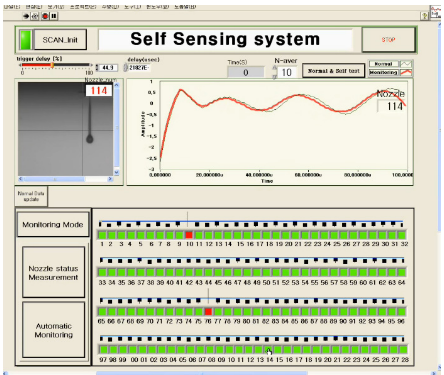

Figure 4. Captured software for monitoring system.

The proposed algorithm uses the self-sensing signal measured at normal jetting conditions as reference data. The reference data are compared with the self-sensing signals measured on a regular or irregular basis to detect possible malfunctions. The self-sensing signals from each nozzle measured at normal jetting conditions (thin line) are compared with the monitoring signals (thick line) of each nozzle. Then, if the monitored signals deviate from the normal condition, the status is diagnosed as a jetting failure.

Another feature of the developed software is to confirm the self-sensing result by comparison with the vision results. When the color button of a nozzle is selected by a mouse click, then the positions of the stages are controlled to measure the jetting behavior of the nozzle using the CCD camera.

The capabilities of the self-sensing signal to detect a malfunction are shown in Fig. 5. The figure shows jetting images with their corresponding self-sensing signals that are typically observed in practice.

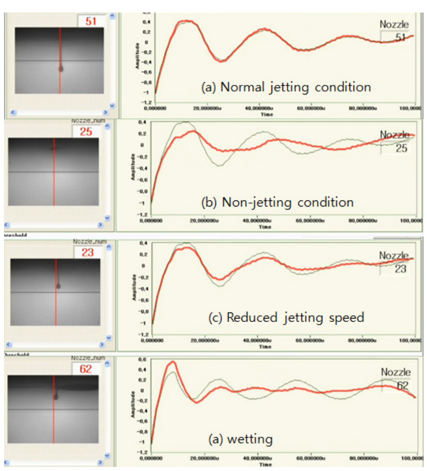

Figure 5. Detection results.

As shown in Fig. 5, the sensing signals were sensitive to jetting status such that a serious non-jetting condition (nozzle 25), a slightly changed jetting status such as a low jetting speed (nozzle 23), and a malfunction due to wetting on the nozzle (nozzle 62) could be all detected. For more details on the proposed method, a video clip is cited in [9].

The capabilities and limitations of self-sensing signals in detecting jetting failures due to other types of inkjet malfunction causes should be investigated further: however, this is beyond the scope of this study. .

Long Term Monitoring Reliability Test

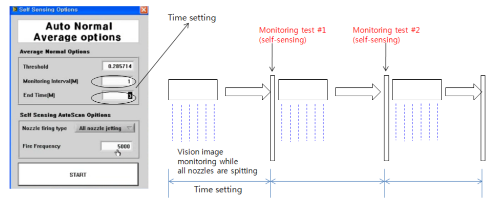

Figure 6. Software for long term reliability test.

We developed software that can monitor the jetting condition via piezo self-sensing at pre-defined times as shown in Fig. 6. During the interval between two self-sensing monitoring period, all the nozzles are set to be jetting at predetermined frequency. During jetting, the motion stage is controlled to acquire each droplet image from the inkjet head. Each droplet image is saved and processed to detect any malfunction. Then, the vision monitoring results are compared to monitoring results based on the self-sensing. The results are automatically compared to determine whether the monitored results from the self-sensing signals are valid as shown in Fig. 7. We are working on a long term reliability test, and have obtained good results from the preliminary test performed in this study.

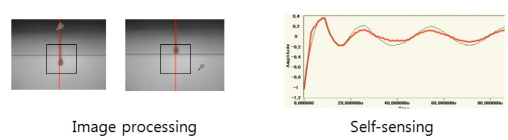

	Image processing	Self-sensing	Detection evaluation
Results (Not XOR)	Normal (True)	Normal(True)	True
	Abnormal (False)	Normal(True)	False
	Normal(True)	Abnormal(False)	False
	Abnormal(False)	Abnormal(False)	True

Figure 7. Scheme for testing reliability.

Discussion and Conclusion

We developed a low cost and high speed monitoring system that can show monitoring results less than 2 s in case of monitoring a printhead with 128 nozzles. We believe that the detection time can be reduced further because most of required time is related to computer speed, and computer speed is increasing. The experimental results show that piezo self-sensing can detect non-jetting failure as well as poor jetting conditions with a slight jetting speed reduction. We compared the monitoring results with vision monitoring. For our long term reliability test, we developed software that can automatically verify the self-sensing results by comparing long term vision monitoring results.

Acknowledgement

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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.