Extending Life of Thermal Inkjet Printheads for Commercial Applications

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Abstract

Thermal Inkjet is a relatively new technology compared to other most commonly established in commercial applications like offset or electrostatic. Thermal Inkjet is wrongly viewed as an unreliable technology. It is usually perceived more suitable for low cost home device appliances. In the present paper, we introduce some of the data showing current trends in thermal inkjet performance and life.

In the area of nozzle health measurement, noticeable progress has been seen with optical and electrostatic devices capable of measuring a single nozzle in less than 2 ms. Such high throughput enables a higher nozzle health monitoring frequency that helps in understanding how nozzle performance varies with time.

Error hiding techniques in multi and single pass printing are also explained along with its potential reliability benefits. Higher nozzle packing capabilities that bring higher printhead resolutions can offer highly reliable systems in single pass printing, very suitable for Commercial Applications.

In summary, nozzle health information can be used to improve noticeably error hiding algorithms and to apply better nozzle recovery algorithms, extending effectively printhead life.

Introduction

During the past 10 years, thermal inkjet performance has improved almost exponentially. It has increased at a similar rate as the one predicted by the famous Moore's law in the semiconductor industry. Higher nozzle packing density (from 300 dpi growing to 1200 dpi), higher firing frequency (from a few kHz to 36 kHz) and wider printheads (growing from 0.17 inches to almost 1 inch) are the fundamental reasons for the increase.

Commercial applications demands higher and higher image quality at high throughput rates. Higher firing frequencies along with smaller drop volumes are the clear enablers for reaching expected image quality in that market. Thermal inkjet printheads show this trend both in reducing drop volume (from hundreths of picoliters to a few picoliters) and in increasing firing frequencies.[1]

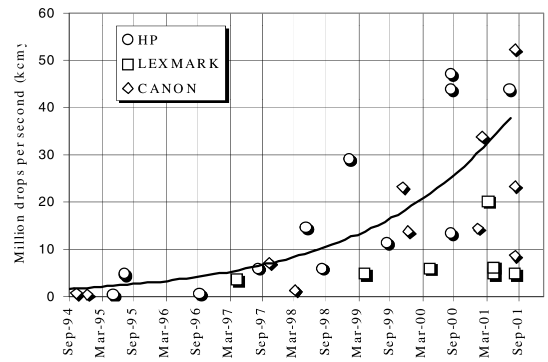

Figure 1. Thermal Inkjet Technology Performance Trends

Life Trends of Thermal Inkjet Printhead

The improvement of thermal inkjet printhead lifes over the last few years is shown in figure 2.

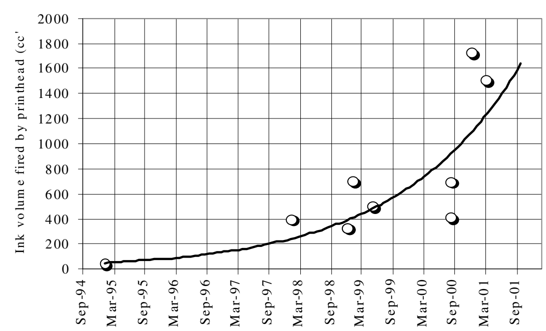

Figure 2. Thermal Inkjet Printhead life trends (source: HP/Canon/Lexmark web pages)

There are several reasons that explain such improvement. The first limitation early printheads had was that they were not refillable. In these situations, maximum printhead life was equal to the total volume of ink the printhead cartridge would hold (usually in the order of 30 to 50 cc's). To overcome this, some printers were designed with a refilling station on board that was able to fill the printhead with another full load of ink, say of 40 cc's. Another step forward was to provide the printhead with an ink regulator that would refill it continuously while maintaining the required pressure inside the nozzle firing chamber. Printhead lifes improved moving from on axis to off axis about 10X.

Printhead design was also another area where key life improvements happened, especially extending resistor life and chosing the correct material set and adhesives to withstand the temperature cycling and ink attacks over long periods of time. Another improvement seen over the last years is the particle tolerant printhead architectures[2] (PTA) that adds robustness to internal contaminant failures. The first PTA designs were more vulnerable to fibers, but by adding a 'barrier reef' particles could not penetrate into the firing chamber.

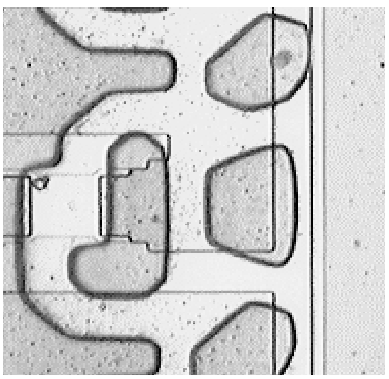

Figure 3. HP particle tolerant architecture with "barrier reef" design

Improvement of resistor life and robustness to internal contaminants helped extending the maximum number of firings per nozzle. On the other hand, material selection improved the time based failures. We don't intend to cover in detail this area on this paper, but overall life increase here was in the order of 2 to 5X over the last 10 years.

Another printhead design that enhances life and IQ at high performance is the increase of nozzle packing density. If the input data is coming at a resolution of 600 dpi, in printheads with 600 npi of resolution, only *n* nozzles will be available to print a row of data in *n* passes. The usage between nozzles will be distributed with twice the number of nozzles if printhead has 1200 npi resolution. This redundancy increases robustness to malfunctioning nozzles on the final output. Latest printhead designs show this trend of increasing nozzle packing density.

All the improvements described above corresponds mainly to intrinsic changes in the printhead design. The printer can help also increase printhead life by measuring nozzle status and applying compensations and corrections to the system.

Nozzle Health Measurement Techniques

In order to be able to correct image quality defects generated by poor nozzle health is key to find a fast and reliable method to measure nozzle performance. HP has developed several measurment systems used in large format and desktop printing devices.

HP Designjet 750 (year 1995) had already an optical device capable of detecting firing drops of a single nozzle at a rate of about 40 ms. To check the complete set of printheads installed in the printer (around 600 nozzles) took around 30 seconds. The sensor consisted in a set of LED, lens and photodiode. When a drop fired by the printhead crossed the light beam, it was sensed by the device. Each nozzle fired one drop several times and the system considered the nozzle failing if most of the detections on that nozzle were false. This device, although effective in measuring nozzle outs, was slow and the light beam width very narrow which was a source of some reliability issues.

HP Designjet 2000 (year 1998) took a different approach. It printed a specially designed pattern which was scanned using a printhead carriage mounted optical sensor. This system was cheaper than the previous one but more than doubled the detection time per nozzle (around 100 ms per nozzle). Again, although effective measuring nozzle health (including potencially misdirected drops), nozzle detection frequency could not be very high due to usability and time consumption reasons.

HP Designjet 1000 (year 1999) improved the optical device used on the 750's. It more than doubled the light beam width with a new set of LED/Photodiode receptor (no lens required) and it was also expanded to be able to detect nozzles from a printhead 0.86 inches long.

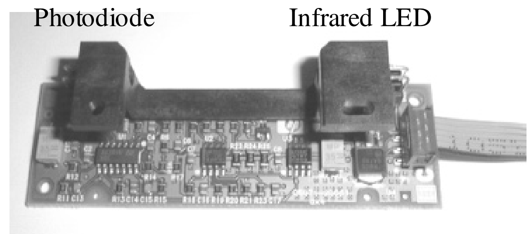

Figure 4. Drop detect used in HP Designjet 1000 and 5000

A new detection algorithm[3] was invented to reduce the detection time per nozzle from 40 ms to 2 ms. In essence, the invention consisted in firing at high frequency several drops so the signal to noise ratio improved dramatically over firing a single drop. The system took about 5 seconds to check more than 2000 nozzles. The improvement on nozzle check speed enabled an increase on detection frequency: it was done at the beginning and at the end of almost every plot. The system saved the last 8 detections per nozzle in one byte and the information was used to optimize error hiding print modes and printhead servicing routines.[3]

HP Designjet 5000 (year 2000) used the same optical design as the 1000's series but made further improvements on the algorithm in order to detect not only nozzles not working at all, but also misdirected or weak drops[4]. The invention consisted in comparing the signals obtained from one nozzle with the average signals obtained from the physical neighbor nozzles. A non firing nozzle would, of course, generate a flat signal. In this case the system had enough memory available to save all the detections performed over the life of the printhead and was used to optimize further error hiding modes and servicing routines.

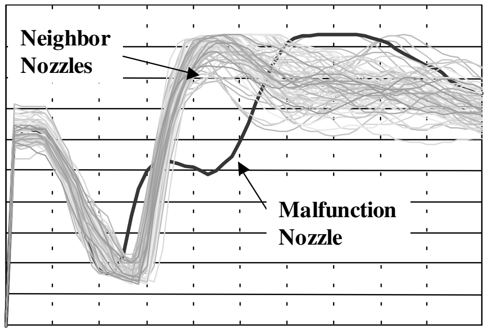

Figure 5. Malfunction nozzle detection on HP Designjet 5000

HP Color Inkjet Printer cp1160 series uses a different drop detection device based on electrostatic charges.[5] Basically, the device creates a potential between the target (on the detector) and the printhead. The potential difference forces a charge on the droplet as it is formed. As the droplet hits the target, the AC coupled amplifier detects the charge transferred. This detector has a slightly slower detection speed than the optical one described above (around 3ms) because detection require more drops per nozzle, but on the other side it is cheaper.

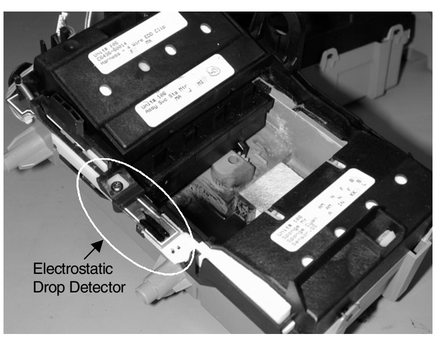

Figure 6. Electrostatic Drop Detector mounted in Service Station. (HP Color Inkjet Printer cp1160)

Other types of drop detection has been investigated, like the acoustic or ultrasonic device that is able to "hear" when a drop has fired,[6] or just a thermal drop detector based on sensing thermal changes resulting from deposition of a drop on top of that material,[7] but none of them has been used yet in a final product.

Error Hiding Techniques

One very effective printhead life improvement comes with the usage of the nozzle health information: error hiding print modes. In essence, the idea behind error hiding is to use a working nozzle in order to print the information that should have been printed by a malfunctioning one. Error hiding methods can be divided in two categories: multi-pass printing or single-pass printing.

Multi-pass Printing

In multi-pass print modes in a typical inkjet printer, the printheads scan over the paper placing a layer of ink at each pass. This means that each row of data is printed at least with a combination of as many nozzles as number of passes used. For example, in the case of a four-pass mode and a printhead with 200 nozzles, the information in the first row could be printed by nozzles 1, 51, 101 and 151 in passes 1, 2, 3 and 4. If nozzle 1 is not working properly, the information that should be printed by this nozzle in pass one could be printed in the following passes by nozzles 51, 101 and/or 151.[8] One of the important limitations of this method is that the back up nozzles could be working at a firing frequency as high as twice the normal firing frequency in that printing mode. Nevertheless, the printhead life improvement achievable by this method can be as high as 2X.

Single-pass Printing

In single-pass print modes there are no extra passes to use as back up option for the malfunctioning nozzle. There are four other ways to get around this: use a different color, use "composite black" (typically a mix of cyan, magenta and yellow that outputs black), reduce the print swath up to where the first nozzle failed or use an adjacent nozzle.[9] From all four, the most promising is the last one, especially when high resolution printheads are used (more than 600 npi - nozzles per inch) coupled with low drop volumes. For example, if incoming data resolution is at 600 dpi and printhead used has 1200 npi, each row of data can be printed with two different nozzles in a single pass printing.

To assess the theoretical reliability gain from a higher nozzle packing density, let´s use the following assumptions:

- Individual nozzles fail following a weibul distribution of characteristic life of 20 and shape factor of 2.5.
- Printhead considered is 1 inch tall, so total number of nozzles is equal to npi.
- Printhead failure criteria considered is one 600 dpi row failing. It means that with a 600 npi printhead, one nozzle out will fail the printhead but with a 9600 npi pen 16 consecutive nozzles should be out before the printhead is considered to have failed.
- Printhead failure criteria follows a binomial distribuion of:

$$Binominal(1,600,weibull(t,20,2.5)^\wedge(npi/600)) \quad (1)$$

Using these set of assumptions, 1200 npi printheads would increase theoretically the printhead life over one with 600 npi by a factor of 4X. A 2400 npi printhead may have an increase of almost 8X and a 9600 npi could reach 14X. This increase assumes that the printer is capable of measuring the nozzle status and use only the working nozzles in a single pass. Another fair assumptios is that the image quality is not degraded by locating the drops in a 1200 dpi grid instead of in a 600 dpi grid. This theoretical result may be contradictory with the thinking that by adding more nozzles, there are more chances for some of them to fail. But the increase of system robustness overcomes this defect.

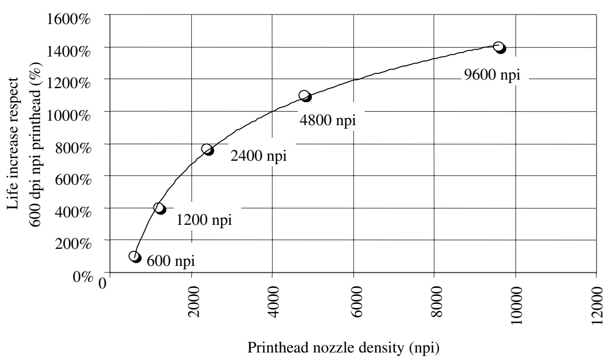

Figure 7. Printhead life increase as a function of nozzle density in single-pass print modes.

The improvement is reduced if a higher shape factor is considered (when nozzle failure is driven mainly by severe aging and most of the nozzles would fail close in time). For instance, by using a shape factor of 4, the improvement from 600 to 1200 npi would only be about 2.1X respect to the 4X predicted before.

On the other side, if nozzle fail more randomly over the life of the printhead (lower shape factors), the improvement would be even more than the ones described with the shape factor of 2.5.

Servicing Optimization

Printhead servicing algorithms consist in a set of procedures to maintain printhead health over its life. Typical treatments include spitting to clear clogged nozzles, wiping sequences to clean orifice surface and priming operations to purge nozzles from hard plugs. When the nozzle health measurement system is fast and inexpensive enough, it is possible to do it before a job starts. The system then can adjust the maintenance operations to recover malfunction nozzles before printing. The trigger of the recovery operations can be based on single detection or based on an historical nozzle health database kept in the printer. The last option damps the system reaction to malfunction nozzles by optimizing servicing only when the failures seen are consistent. It can also stop the optimization routines to recover the malfunction nozzles after several failed attempts. If the system detects too many malfunction nozzles, image quality will be at risk. The printer then can:

- Automatically stop so user can either decide to acknowledge the loss of quality or stop the job and replace failing printhead or attempt to recover further the failing printhead,
- Increase automatically the number of passes to deliver the expected quality but at a loss of performance.

These set of algorithms are very helpful to improve printer unatendedness: the user can send more plots in a job and be more certain that the final output will meet the expected image quality or the system will stop if it is at risk.

A further improve of the algorithm would come if enough historical data is saved in the printer. In this case, the printer can analyze the pattern of the malfunction nozzles to assume a particular failure mode and select the best recovery option for that type of failure.[4]

An example of possible information that could be gathered and saved in the printer is shown in figure 8, where it is depicted which nozzles where failing at different points in life. In the Y-axis, we show the nozzle number (from low to high). In the X-axis, we show the printhead life.

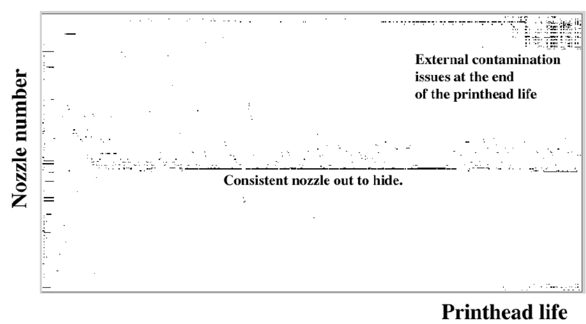

Figure 8. Map of malfunction nozzles over printhead life

By analyzing the map, evident patterns are extracted such as the permanent nozzle defect in the center or the grouped intermittent malfunction nozzles that were visible at the end of printhead life[4]. The failing nozzle in the center was related to a hard ink plug that was hard to recover. The malfunction nozzles in one edge of the printhead were related to external contamination on nozzle plate. As it is seen, these nozzle maps can also be very helpful to understand the nozzle failure mechanisms of inkjet printheads, especially after correlating failure analysis with these maps.

The printhead life increase obtained by these optimizations could be between 1.5 to 2.5X.

Another possible use of the malfunction nozzle information is the printhead life gauge that would help the user to diagnose which printhead is the source of possible image quality defects seen in the print outs.

Conclusion

This paper summarizes some of the improvements seen in performance (from a few thousand drops per second to 50) and life (from a few cc´s to liters of ink) of thermal inkjet printheads.

It also describes several nozzle health measurement methods already used in some printers, like the optical or the electrostatic drop detectors, and how they have evolved with time to improve its performance.

It also shows how by measuring nozzle health performance, the system can compensate some of the nozzle failures extending even further printhead life thanks to error hiding methods either in single and multi pass printing. It has been analyzed the theoretical increase of printhead life in single pass printing conditions by moving to high packing density printheads (higher than 600 npi).

Optimization of servicing algorithms is also made available by the nozzle health measuring systems, improving further final printhead life and image quality consistency.

Acknowledgement

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Biography

Xavier Bruch received his M.S. in Mechanical Engineering from Escola Tecnica Superior d'Enginyers Industrials de Barcelona (UPC) in 1988. He has worked in several engineering consultant companies (Ove Arup in London and JG & Asociados in Barcelona) and for the last seven years, he has worked for Hewlett-Packard in the area of writing system reliability and image quality of inkjet large format plotters. He has published several patents in this field.