HP Inkjet Large Format Page Wide Array: Solution for Drop Detection and Nozzle Replacement

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Abstract

The new HP Inkjet Page Wide Array technology[1] delivers breakthrough speed via an array of inkjet nozzles covering the entire paper width. Printing is done in a single pass, which makes nozzle health critical to meet product image quality and reliability requirements. A nozzle or groups of nozzles failing to eject drops create visible straight white lines on the printouts. The nozzle array contains a total of more than 200,000 nozzles.

There is a challenge compared to current large format inkjet printing systems. First, single pass is much more sensitive to failing nozzles than multi-pass. Secondly, the number of nozzles and the productivity requirements are an order of magnitude higher. Existing solutions for nozzle health measure and compensation are no longer valid.

The paper describes a new solution (hardware and algorithms) developed to measure and compensate for those nozzles that may temporarily or permanently fail to eject drops. The solution developed highly reduces time to measure, it allows checking 200K nozzles in 90 sec. It is easily scalable to different types of print heads and array sizes, it can even also work in scanning systems.

Nozzles are analyzed regularly and printer classifies them based on historic measures. Compensation algorithms include nozzle substitution using adjacent nozzles or nozzles of a different color that are in line in paper axis direction. Specific cleaning routines can be self-triggered to guarantee proper printout quality. Customer is informed about the status of the quality of print heads.

Introduction

The new HP Inkjet Large Format Page Wide Technology[1] Printers is a family of high-productivity color printers for technical graphics and reproduction services. An array of stackable inkjet print heads, also known as print bar, covers the entire paper width. The technology is easily scalable in size, productivity and image quality with a different number of modules per print bar or number of print bars. Improved stackability is obtained by the "S-shape" design of the modules. This shape allows them to fit together in a compact, linear print bar.

Compared to previous large format HP DesignJet printers, there is no need to move print heads while printing. The print bar keeps static and paper moves below it, which results in a much higher productivity.

The first products using HP Large Format Page Wide Technology are HP PageWide XL 8000, 5000 and 4000 Printer series. They contain a single 40-inch wide print bar, built with 8 print head modules. It is a 4-color pigment ink system that can print up to 30 D/A1 pages per minute.

Single-pass printing quality is very sensitive to small dot placement errors or missing dots. Therefore, keeping nozzles with good drop ejection performance is key.

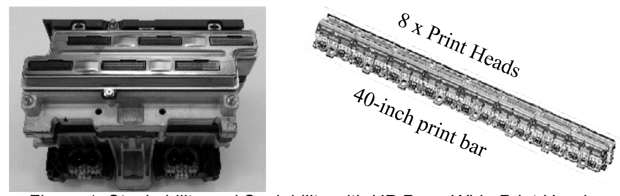

Figure 1 Stackability and Scalability with HP Page Wide Print Heads

Most of current HP large format printers have a nozzle health measurement system. However, those solutions fall short for HP Large Format Page Wide Technology printers. A new drop detector solution has been developed for this family of printers.

Existing Nozzle Health Measurement Systems

To measure nozzle health, HP has developed several measurement systems used in large format and desktop printing devices.

Single channel optical drop detector devices are the most used. In most printing devices a single sensor is used to measure all nozzles. The size, parts and embodiment of the sensor have been evolving to accommodate to the evolution of print heads and printers. The basic functioning principle however stays the same. The print head carriage positions over the sensor and each nozzle is successively evaluated.

In optical drop detectors, each nozzle fires a burst of drops through a light beam. An infra-red LED sources light onto a photodiode. The burst of drops provides a shadow as they pass the photodiode, decreasing its output current. Firing parameters are chosen to ensure the change in signal (photodiode output) is large enough to indicate the presence of drops over noise present in system.[2]

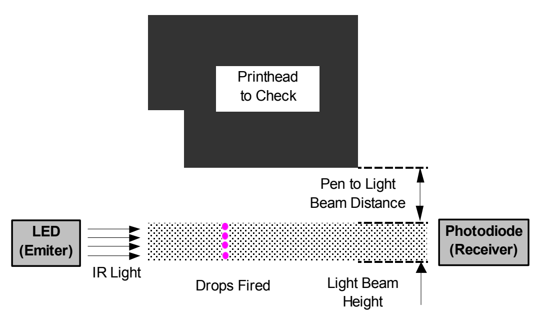

Figure 2 Schematic Diagram of Optical Drop Detection[2]

Another method for drop detection is measuring drop electrostatic charges[3]. An implemented solution is firing drops on a sensing plate that is at a potential difference from the print head. As the droplets hit the sensing plate, the AC coupled amplifier detects the charge transferred, and therefore, the presence of drops. Sensing plates require periodic cleaning. And advanced design disposes the sensing plates parallel to the drop trajectory, thus not needing for a cleaning system.[4]

None of the existing drop detector solutions was valid for Page Wide Array Technology. The number of nozzles per printer dramatically increases to enable outstanding productivity, an order of magnitude above current large format HP DesignJet scanning systems.

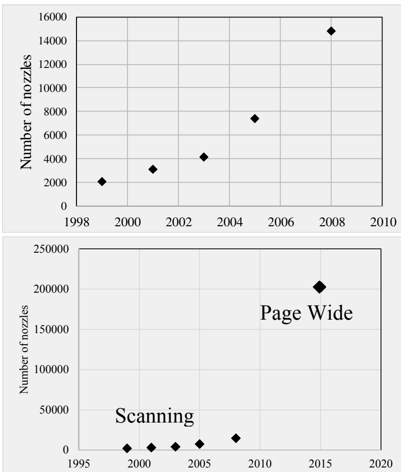

Figure 3 Evolution of number of nozzles per printer

Drop Detector Requirements

This section of the paper refers to the requirements and specifications of the drop detector solution for HP Large Format Page Wide Technology.

To support sustained high productivity printing, nozzle health evaluation of the 40-inch print bar, which is a total of 202,752 nozzles, has to be accomplished within 90 seconds.

Scalability describes a design philosophy where modules are repeated along and across the print zone to support a variety of product sizes and features. The drop detector design needs to be scalable to support this. Among others, it needs to be able to work with a wide variety of drop weights (e.g. from 4pl to 18pl), different types of ink, colors, print bar sizes and nozzle packing density.

A nozzle that is not ejecting drops can eventually lead to print quality artifacts. Drop detector needs to be very precise at identifying clogged nozzles. The specification of the error rate for failing to detect a missing drop is 0.01 ppm.

Drop Detector Solution

There were different solutions considered. First solution was a fixed optical drop detector below the print bar as shown in Figure 4. Laser technology and optic lenses would be used to achieve a

Figure 4 Fixed 44-inch Optical Drop Detector Concept

coherent 44-inch light beam. The operating principle would be similar to existing optical drop detectors, drops ejected by each nozzle do cross the light beam and are detected. The advantage of this concept is that it does not require moving parts. However, this solution was discarded because of being too slow, very few nozzles could be measured at the same time.

To enable high speed nozzle health measurement of a print bar of more than 200,000 nozzles, a compact solution of 12 optical sensors working in parallel has been invented and designed[5]. The drop detector is scanned at a constant speed of 1.1 inch/sec below the print bar. As the drop detector advances, each of the 12 optical sensors is measuring a different nozzle. After going below the whole print bar length of 40-inches, half of the nozzles are measured. A second pass is needed to complete the measure of all nozzles of the print bar.

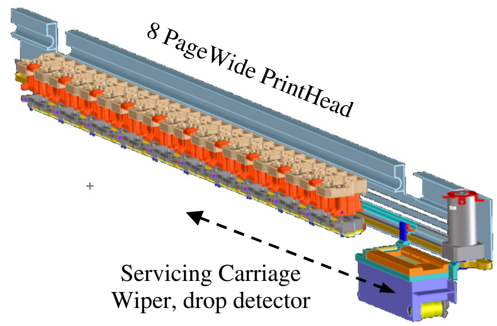

Figure 5 Print Bar and Servicing Carriage with Drop Detector

The drop detector is installed on top of the servicing carriage, which also contains a textile web wiping system for cleaning print heads regularly and a sensor for print head alignment and color density calibration. An elevation system is implemented to minimize the distance between nozzle plate and sensors when the drop detection process takes place. There is an impelling system, motor, gears, belt and encoder that moves the carriage along the print bar. The whole print bar has the capability to move vertically. Before doing a drop detection, the print bar raises from the printing position to allow the servicing carriage slide below it.

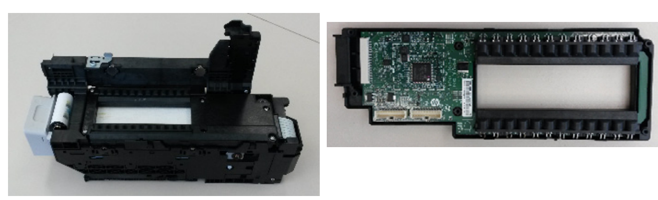

Figure 6 Servicing Carriage and Drop Detector (array of 12 sensors)

The design is easily scalable to other product sizes and productivity requirements. Products with more print bars can just replicate the servicing carriage and drop detector for each print bar. Smaller or bigger products can also vary the number of sensors to adapt to the product size and productivity requirements. The sensor can also be used in inkjet scanning products. The distance between 2 consecutive sensors is only 9.4 mm, which allows for a very compact design. As an example, compared to HP DesignJet T7100 series, the volume per optical sensor is 50% reduced.

A single optical drop detector sensor consists of a LED [Light Emitted Diode] - photodetector pair. Both optic components and windows have been evolved from previous optical drop detector designs to improve detection speed and minimize number of drops needed to measure each nozzle.

The LED is a high power red LED with a small half intensity angle in order to have a narrower beam light width along all the detection area. The PD [photo-detector] has also a small half intensity angle in order to avoid interferences with the light of neighbor light beams.

The diameter of droplets is approximately 1/200 of the light beam width. Without imaging lenses, it would not be possible to image individual droplets. However, the functioning principle is not imaging a droplet, but measure the field intensity change generated when droplets pass through the beam light. The PD detects the transition and is amplified by the electronics that are behind it. The transimpedance amplifier and the pass-band filters translate the current information to voltage information resulting in a pulse response.

The result of the evolution over previous optical drop detector designs is an increased performance. It improves signal to noise ratio on lower firing frequencies, which are more similar to actual printing conditions, and reduces the number of drops per nozzle needed. Figure 7 shows the statistical distribution for sensor noise and sensor response amplitude when drops from one nozzle are detected. The new design provides larger and less variable signal amplitude.

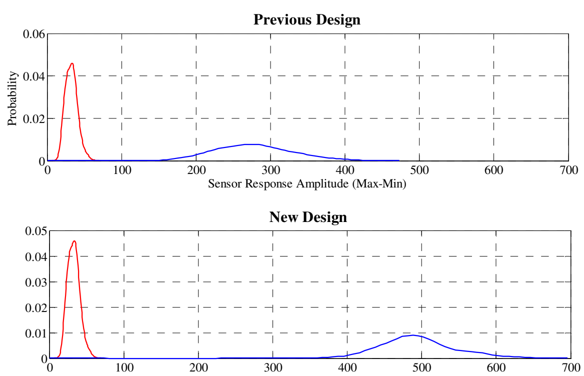

Figure 7 Noise (red) and Signal (blue) of previous drop detector and new design.

Missing Nozzle Detection Algorithm

While drop detection takes place, at a given moment there are 12 nozzles being measured. Each nozzle ejects a burst of drops on one of the 12 sensors.

For each nozzle, 44 samples at 40 kHz are analyzed after analog to digital conversion step. Figure 8 illustrates sensor responses to good working nozzles and to noise or non-working nozzles. Signal amplitude is computed as difference between maximum and minimum value and it dictates whether ink has crossed the light beam and therefore drops are being ejected. For each nozzle the signal amplitude is compared to a threshold. If it is larger than the threshold, the nozzle is ejecting drops. This is enough for identifying nozzles failing to eject drops.

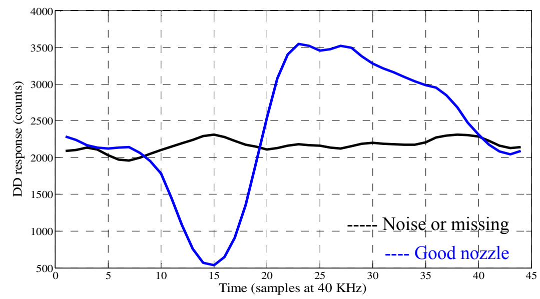

Figure 8 Signal for working nozzles and nozzles not ejecting drops

A further improvement of the algorithm that has been implemented in some products is analyzing the actual shape of the signal, not only the amplitude[6]. By comparing to a reference shape of the signal, nozzles that eject abnormal drops like weak or severely misdirected can also be identified.

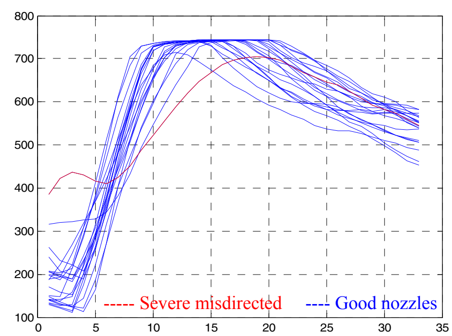

Figure 9 A severe misdirected nozzle (red signal) results in a signal shape different from good operating nozzles (blue signals)

The number of drops and firing frequency ejected by each nozzle dictate how many drops will be crossing the light beam a given period of time. This has a direct impact on the sensor signal amplitude as shown in Figure 10. A relevant point also is that the more drops or less frequency, more time is needed for detection of a nozzle. In the case of HP Large Format Page Wide Printers, the operating point for drop detection is 4 drops per nozzle at 18 kHz.

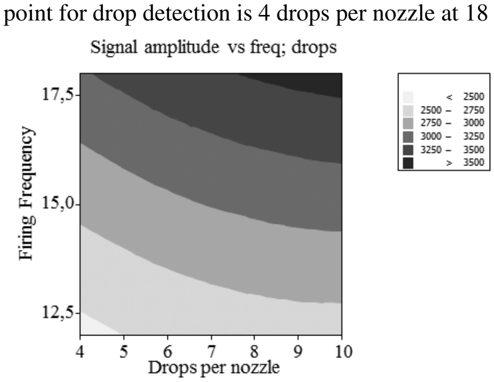

Figure 10 Signal amplitude vs drops per nozzle and firing frequency

Sensor Positioning and Synchronization

The relative position between an optical sensor and the nozzle to be measured has a large impact on the amplitude of the sensor response. This is true both for print bar axis and vertical axis directions.

On the print bar axis direction, the sensitivity of the optical beam is optimum at the center zone and starts degrading progressively at distances larger than 1mm from the center. It is recommended to work assuming a window of 2 mm. The mechanical tolerances involved include the sensor itself, the transmission system and the print head positioning. To facilitate easier manufacturing and less demanding mechanical tolerances, a calibration of relative positions between drop detector and print heads is done at the end of the printer assembly process. This calibration lasts for the life of the printer.

To calibrate the position of a sensor with respect to a print head, the sensor is positioned under the print head. Drops from a number of nozzles that cover a wider area than the sensor are successively measured. Drops from nozzles outside the light beam are not detected. Drops from nozzles close to the center of the light beam result in maximum signal. Analyzing signal amplitude from all nozzles measured results in the sensor sensitivity profile, as shown in Figure 11. The center is identified as the optimum position for drop detection, and therefore the relative position between the center of sensor and print head is defined. This position is then encoded in the printer firmware and is valid through printer life.

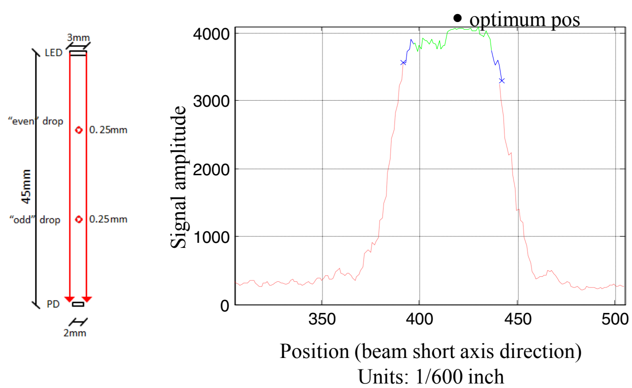

Figure 11 Sensitivity profile of LED-PD pair.

The detection of all print bar is done while the array of drop detector sensors moves below the print bar at a constant speed. It is required to synchronize firing of the nozzles with sensor position in order to have droplets passing through the light beams in the optimal position at the right time.

As nozzle packing density (1200 nozzles per inch) is higher than the resolution of the position encoder, the drop detection process is based on position and time synchronization.

Every position step size, the detection is synchronized with the carriage movement. The firing of the group of nozzles between two consecutive position steps is triggered based on a timer.

An example would be the step size being 6 encoder units and the group of nozzles in that step is 4 nozzles. In each step, it is launched the detection of 4 nozzles. The process is done in parallel for the 12 sensors.

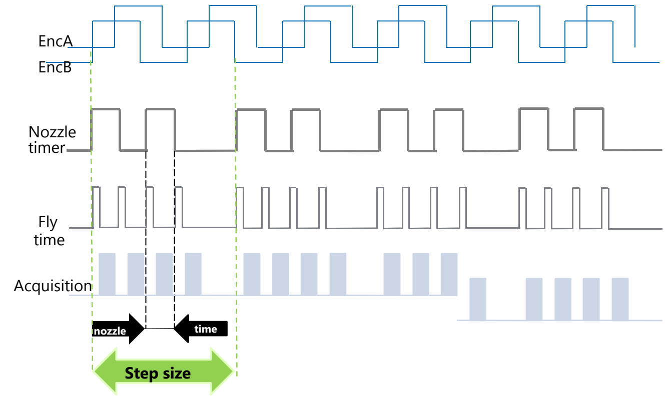

Figure 12 Position and Time Synchronization

Distance from nozzle plate to sensor is another critical parameter. Drops are ejected at a certain velocity, which progressively decreases as they move far away from the nozzle plate. Also main drop can be split in secondary drops, which have a lower velocity. Depending on the distance from the nozzle plate, sensor will see a different group of drop sizes and velocities. It is not recommended that the sensor is very far from the nozzle plate because small secondary drops take more time to reach the sensor which causes a smaller signal amplitude and requires more time for stabilization. HP Large Format Page Wide Printers operate at a distance of 3.8 mm.

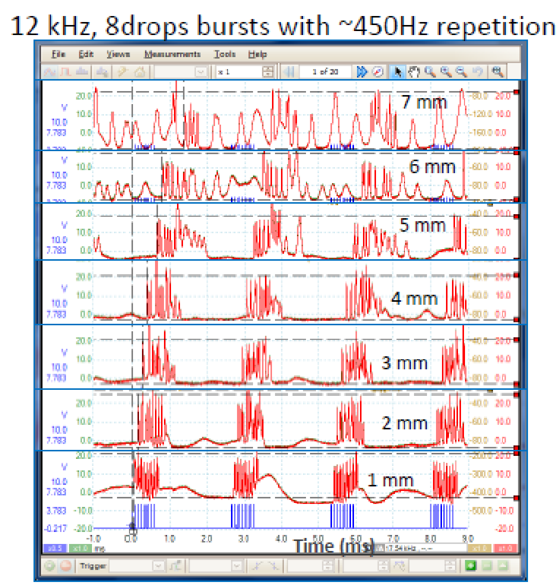

Figure 13 Evolution of sequence of drops with distance from nozzle

Laboratory measures shown in Figure 13 have been done to understand the evolution of a burst of drops as it moves away from the nozzle plate. The sampling has been done at a frequency of 400 KHz, which is 10 times higher than the one used in drop detection. The further from the nozzle plate, the train of drops starts to spread and eventually merges with the drops of the train of drops from the next nozzle to be measured. Up to 4mm distance, the conditions for drop detection are good, but over that distance, there is progressive degradation and signal/noise ratio is reduced.

Enhanced System Reliability

Drop detection is triggered automatically by the printer. It adapts to the print mode and paper type selected by the customer. Missing drops are considerably more visible in uniform area fills that in engineering and CAD drawings. Since the expectation for printing CAD is maximum productivity, drop detection is triggered less frequently than when printing renders or posters. For the latest, customer prefers slower more robust printing on higher quality and more expensive paper. On those cases, drop detection is done more frequently to ensure print quality is optimized.

To optimize print quality and extend print head life, error hiding print modes are used in HP Large Format Page Wide Printers. The capability to produce high drop rates and its high nozzle density of 1,200 nozzles per inch enables active nozzle substitution to suppress the effects of failed nozzles. If a given nozzle is detected as failing, it is substituted by its neighbor nozzles, which then eject drops at appropriate locations to compensate for a missing nozzle. It is unusual that a few neighbor nozzles fail at the same time, but if that happened, still there is the option to substitute those by nozzles from other colors that are in line in paper axis direction. The top part of Figure 14[1] illustrates these active nozzle substitution concepts.

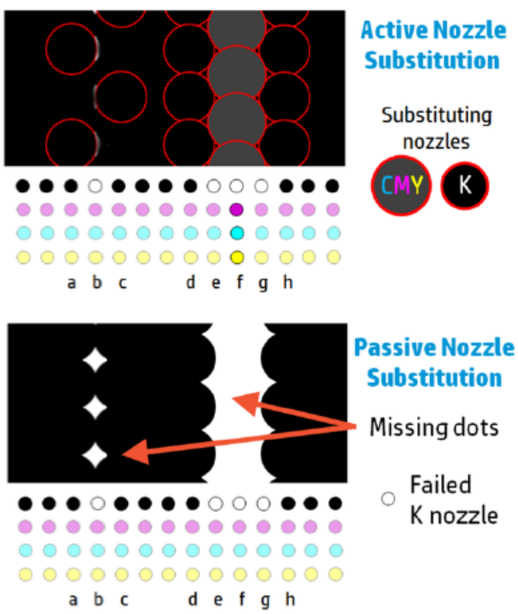

Figure 14 Nozzle Substitution

If no active nozzle substitution is done, still the visibility of a single nozzle failing is reduced on papers with small dot spread and even not visible on papers with more dot spread, such as bond papers. This is referred as passive nozzle substitution. Thanks to a high nozzle packing density, dot spread is larger than the distance between two consecutive nozzles, and therefore when a nozzle fails it does not result in a continuous white line along the page.

Failures are not necessarily permanent. For example, a nozzle may be clogged by dust or dry ink and it can work properly again after a cleaning process is triggered by the printer. The nozzle substitution algorithm is no longer needed. Printer keeps track of the last drop detection measurements of every nozzle and classifies them as good, temporarily, intermittently or permanently failing.

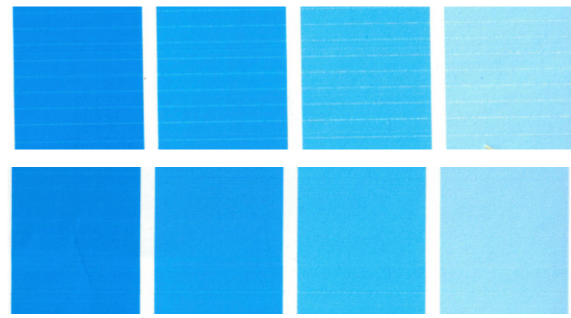

Figure 15 A series of two consecutive nozzles failing without and with active nozzle substitution

Print head servicing routines such as wiping nozzle plate surface or spitting a few drops per nozzle are automatically triggered by the printer. These maintenance servicing routines guarantee print heads are in good condition throughout their life. The frequency and amount of servicing routines may be adjusted based on drop detector information. This helps to optimize ink usage and to increase both the duration of cleaning cartridge and printer productivity. For example, if a certain number of nozzles in a print head is not operating properly, specific cleaning routines can be triggered only for that print head and not for the whole print bar.

At any moment, customer can consult through the front panel the status of each print head in the printer. Print heads age and towards their end of life there may be nozzles that fail to eject drops, Based on drop detector measures, and taking into account the quantity and location of defective nozzles, the customer is advised whether print head works at optimum condition or else it is recommended to monitor the output print quality for contents that demand high quality.

Drop detector is also a powerful tool for development and optimization of printer servicing hardware and algorithms. Throughout the printer development life cycle, drop detector measurements are stored for analysis.

Conclusion

A drop detection system in the printer and the associated servicing and error hiding algorithms are key for maximizing output print quality and optimizing cost of operation.

The new family of HP Page Wide XL Printers delivers the highest color productivity for technical graphics and reproduction services. A fast and highly reliable drop detector solution has been developed to meet those high productivity standards and still provide a robust printout quality.

Scalability is a key concept in efficient product development. The drop detector solution designed can easily scale into many other product configurations with different size, number and type of print heads, ink formulations and many others.

Single-pass printing is more sensitive to missing nozzles than multi-pass printing. Drop detection identifies nozzles that may be transiently or permanently clogged. Error hiding algorithms maximize print quality by substituting nozzles that do not work properly by neighbor nozzles that work properly.

Drop detection results are also used to adjust ink and time spent in automatic cleaning routines. This results in a more efficient system and lower cost of operation.

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Biography

Jose L. Valero received his M.S in Mechanical Engineering from Escola Tècnica Superior d'Enginyers Industrials de Barcelona (UPC) in 1999. He joined Hewlett-Packard in 2000 and since then has worked in the development of the writing systems of a variety of large format inkjet printers. Most recently he has contributed to the new HP PageWide XL technology.

Laura Portela holds a M.S. in Telecommunications Engineering from Universitat Politectnica de Catalunya (UPC) in 2006. She joined Hewlett-Packard in 2006 as electronic engineer focus on sensor development, designing and integrating embedded systems in large format inkjet printers.