HP's Optical Media Advance Sensor (OMAS)

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Abstract

Precise and accurate motion control of media through a printer is a critical element of image quality. Media advance errors of a fraction of a dot row can be visible to the eye as banding.

Competitive pressure for higher print quality and higher throughput have driven inkjet printer designs to use wider print swaths in combination with reduced-pass print modes that together place unprecedented precision and accuracy requirements on the motion control of the media through a printer.

To meet this demand and overcome the practical limit of indirect measurements from encoder-based systems, HP has invented and developed a sensor that provides a direct measurement of the actual media advance based on the Optical Navigation Technology: the HP Optical Media Advance Sensor ("OMAS").

OMAS is a tiny, custom "machine vision" system that takes digital images of the microscopic texture on the backside of the media as it moves through the printer. Successive images of the surface texture are correlated in real time to compute the media motion with unprecedented accuracy.

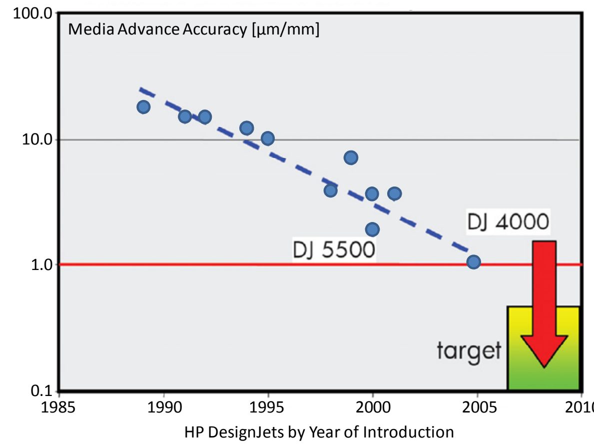
Because OMAS provides a direct measurement of media advance, it eliminates many variable and complex factors that affect the media drive system. It facilitates to achieve accurate vector lengths, consistent image quality and better line straightness for a broad diversity of printing media and maintain them across a wide range of temperature and humidity conditions, providing dependable performance over the printer's life in production printing environments.

HP's Optical Media Advance Sensor and the associated navigation and servo correction algorithms first introduced in the HP Designjet Z6100 and since continuously upgraded in following Designjet printers to enable faster media move and improved system reliability over broader operating ranges, can equally be beneficial to other systems with very precise and accurate motion control requirements at high throughput.

Advances in Accuracy

Competitive pressure for higher print quality and higher throughput have driven inkjet printer designs to use wider print swaths and longer media advances between printhead scans. This has led to continuous improvement in media advance accuracy. Since 1990, HP has improved the accuracy of encoder-based media advance systems in HP Designjets by a factor of 20. The trend is shown in the chart below.

The accuracy of encoder-based systems that indirectly measure media motion has a practical limit at about 1.0 micron/millimeter (0.1%). At this level, and for any further improvements of this technology, high mechanical precision in all drive system components is required, and this drives up manufacturing cost without assuring that high performance can be maintained



over the life of the printer, over temperature and humidity extremes, and for all types of media.

To achieve their potential for high print quality at high throughput, current and future developments in printhead technology depend on precise and accurate media advance over larger distances. For example, accuracies of 0.4 to 0.5 microns/millimeter are required for the long media advances of HP Wide Scan Printing technology. This requires a performance breakthrough that exceeds the practical limits for indirect measurement of media motion: another 5X improvement in media advance accuracy is needed.

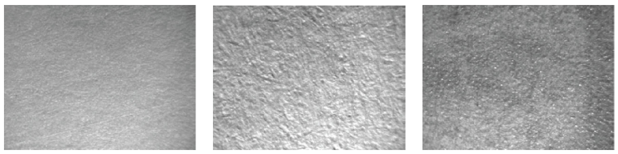
OMAS - Direct Measurement of Media Motion

Direct measurement of media advance eliminates many variable and complex factors in the media drive system. It allows control based on the actual motion of the media.

Position measurement using mechanical devices, as could be implemented through a tracking roller that contacts and moves with the media, retain many of the limitations of indirect measurements: errors induced due to media slippage, harmonic effects in rollers and rotating parts, contamination by paper dust, etc. In contrast, the HP Optical Media Advance Sensor ("OMAS") provides a direct measurement of media motion and delivers a breakthrough in accuracy over conventional encoder-based media advance systems.

OMAS is a tiny, custom "machine vision" system placed inside the vacuum beam, underneath the print platen of HP Designjet Series printers. The sensor window can be seen on the printer platen.

OMAS works by taking digital images of the microscopic texture on the backside of the media as it moves through the printer. Successive images of surface texture are compared to compute the vector of motion. Since the signal used for position measurement is provided by the microscopic structure inherent to the media itself (e.g. paper fibers), no printed tracking patterns or artificial induced marks are required.



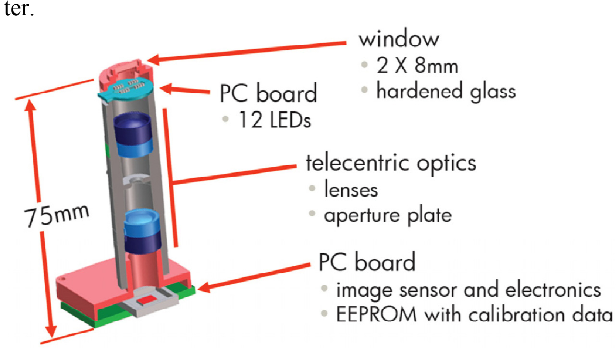
Texture at the back side media surface as seen by OMAS

The patterns of the surface structures, shown in the figure under the illumination and magnification used by OMAS for three types of media, provide reliable navigation at the full media advance speed of the HP Designjet Series printers.

OMAS Setup

The heart of the OMAS is HP's unique, custom electro-optical sensor module and image processing algorithms. The technology was invented and developed over a multi-year collaboration between HP Large Format Printers Division (Barcelona, Spain) and HP Laboratories (Palo Alto, USA).

The Sensor Module consists of an optical assembly and printed circuit board. The optical assembly, which is placed inside the vacuum beam of the printer, underneath the print plate, has a hardened glass window with anti-reflection coating that is normally in contact with the back side of the media to establish focus, an array of 12 bright red light-emitting diodes (LEDs, 1 x 0.5 mm size) to provide adjustable and uniform illumination, and a lens system and aperture plate arranged in a 1:1 telecentric magnification system to project an image onto the image sensor. Telecentricity is fundamental to ensure that the magnification of media features remains constant independently of the media moving upward and away from the platen as it is printed and fed through the printer.



Details of Optical Media Advance Sensor – Sensor Module

A small printed circuit board at the bottom of the module holds a custom image sensor (192x512 pixels with two independently programmable windows of interest) designed for high-speed imaging and fast data transfer, control electronics for the sensor and LEDs, and an EEPROM with factory calibration data for the sensor and optics.

Relative linear and angular positions of the optical components are precisely aligned during manufacture of the Sensor Module and secured in place with UV-curable adhesives for long-term mechanical stability.

A purposely designed assembly tool is required to meet the tight adjustment specifications: Accommodate the system focus within 20µm, orient image sensor and optics enclosure within ±0.03º to warranty proper sensor orientation in the media advance direction and ensure that all the sensor pixels are correctly focused through ±0.15º accurate co-planarity between the top window and the image sensor plan..

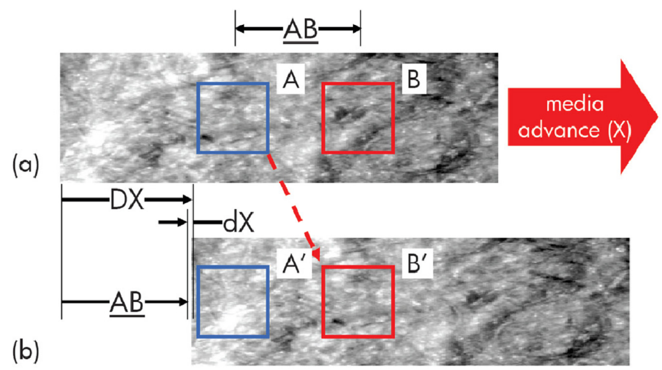
The Sensor Module is connected through a ribbon cable to a custom circuit board containing a digital signal processor (DSP), memory, and interface circuitry. The DSP determines the precise motion of the media from successive images received from the Sensor Module, and this information is used by the printer's media motion control system.

Acquisition and Detection algorithm

The Optical Media Advance Sensor observes the media at two positions spaced a precisely known distance along the media advance direction, X, shown as Windows "A" and "B" in Figure (a).

These windows are actually separate arrays of pixels on the same image sensor chip. This simplifies sensor module design and assembly, and ensures that the windows maintain a precise separation AB. This physical distance is programmable and has been adjusted to 3.5mm considering the alignment of the lenses, location of the image sensor on the PC board with respect to the optical axis, and the actual pixel area used for the windows "A" and "B". AB is stored in the sensor module's EEPROM during manufacture.

The figure below explains schematically and in more detail how OMAS works by comparing two sets of images of the media surface. Figure (a) shows the media at a first position, where patterns of media surface texture are seen in Windows A and B.



Schematic of Operation
(a) media at first position (b) moved a distance DX in the X-direction

The LEDs flash to freeze the motion. This gives high illumination intensity while minimizing LED heating and allows the media to move at any speed up to the HP Designjet's maximum advance rate (~6 inches/sec) during measurements.

Images A and B are captured by the Sensor Module and stored for processing on the DSP board.

Figure (b) shows the media at a second position after moving a distance DX. DX is not exactly the window separation AB, but the combination of AB and the small distance offset dX found when comparing the image in Window B' to the image in Window A with the detection algorithm described below

$$DX = AB + dX$$

(Notice, for example, that the same dark spot appears in the lower-left of Windows A and B' and most of the rest of the pattern is seen as well.)

A predictor mechanism instructs the system to acquire a new set of images when the paper has advanced, approximately, the window separation distance AB. This signal, triggered through a rotary encoder on the printer's final drive roller, ensures that features seen in Window A have moved into the field of view of Window B' and causes the system to acquire a new set of images.

The image from Window A' will be used later as reference when the process is repeated.

With the distance AB being approximately 3.5 mm, measurement of a complete media advance usually requires "N" DX steps: DX_1, DX_2… DX_N. The media does not stop and start on these steps: it moves continuously in the sensor's field of view while images are captured in the Windows A and B. A media advance can be as long as 101mm with HP Wide Scan Printing Technology in HP Scitex LX-series printers, so about 29 steps are needed for the longest media advance (i.e. N = 29). Fewer steps are required for the shorter advances used in high quality print modes.

The total distance X moved by the media is simply the sum of the N individual steps:

$$X = DX_1 + DX_2 + . . . + DX_{N,}$$

where $DX_i = AB + dX_i$ designates the motion vector during the i-th step. The offset dXi will generally be different for each step, and can assume both positive and negative values.
X is the final distance to be used by the paper advance motion control system to correct the advance error.

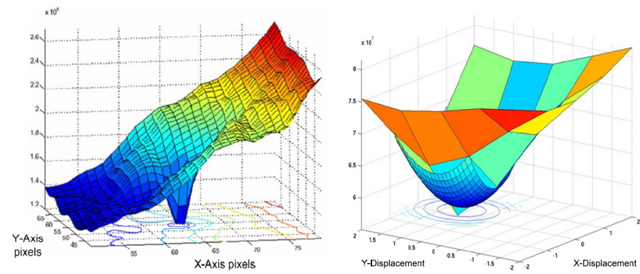
Detection algorithm

The Optical Media Advance Sensor uses HP's proprietary algorithms evolved from the Optical Navigation Technology developed originally for the handheld scanner HP 920 Capshare [1] and optical mice [2], [3]. In a few words, this technology provides a way to obtain dX with high precision by finding the local cross-correlation minimum between images A and B'.

Splitting the algorithm into two steps permits real time processing with the DSP in OMAS. First, a phase correlation algorithm [4], with high robustness to illumination variations, motion blurs differences and optimal in terms of processing power, is used to determine dX within a 2x2 pixel area. Subsequently dX is refined by adjusting a quadratic form to the cross-correlation surface minimum and determining its center. Given enough image contrast, which is optimized adjusting the system optics and tolerances during the OMAS assembly procedure, this process is capable to yield results with accuracy better than a fraction of a single pixel on the image sensor.

Correction strategies

The way the OMAS measurements have been integrated in the media advance correction workflow has evolved over time, from the first printer incorporating the sensor in 2007, the Designjet Z6100, to current HP Latex systems.



Correlation surface *Quadratic form adjustment*

Originally, the measurement of the optical sensor was integrated as part of the media servo to improve the accuracy and repeatability of the encoder mechanism through a feedback mechanism. The advance error measured and accumulated during an initial phase was used to determine the length of a compensation (sneak) interval, shortened or lengthened as needed, at the end of the advance movement. During the compensation phase, after the error feedback, media moves at low speed, which may slightly impacted system throughput.

So called Dynamic Media Factor (DMF) based strategies were recently adopted to overcome original limitations. In addition to the media servo feedback, OMAS measurements are used to adjust dynamically the parameters of the advance model that dictates the corrections during the compensation phase and when OMAS measures are not valid. Incorrect measurements will not be included for the adjustment. The last valid measurement will be used instead. Beyond the improvement in robustness and accuracy, this new advance correction scheme extends media versatility, as it enables the navigation of media that were not navigable in the past (e.g. Backlit) through the relaxation of OMAS failure criteria.

A radically different compensation method has been designed to extend the versatility to highly elastic substrates, where the advance errors during the sneak phase are neither negligible nor predictable. This approach completely eliminates the sneak phase, and the direct interaction of the OMAS measurements with the real time media advance servo, integrating the advance correction at printing system level. Instead of correcting the advance of the media, the printing swath is repositioned within the printhead to compensate for the measured error. This offset is adapted for each swath depending on the advance error, so that subsequent swaths are perfectly aligned. To enable the integration of this strategy several capabilities of the pipeline ASICs had to be enhanced.

The final choice of a particular compensation strategy depends on the media drive specifications in the design range of customer applications.

Current Performance and Limits

With a breakthrough accuracy better than 0.4µm/mm, with errors, measured as |avg| +3 sigma, below ±20µm in a 50mm media advance, the OMAS is 2- to 10-times more accurate than a conventional encoder on the final drive roller and enables high print quality, banding free plots at 1200 dpi resolution while taking full advantage of the unprecedented throughput of new print systems.

Other significant advantages of the OMAS are the stability achieved across changing environmental conditions and that the targeted accuracy is sustainable across a wide range of printing media:

When classifying the different sources that contribute to the media advance variability automatically compensated by OMAS, the effects of relative humidity and media range on the coefficient of friction between paper and media drive components are by far the most outstanding.

The media versatility expected by customers requires supporting media sets that typically extend from thin natural tracing papers (for CAD drawings) to thick canvases (for specialty graphic application). Diverging media properties within this set induce advance variations in the 7mm/m range.

On the other hand, relative ambient humidity drives changes in the media advance at the 5mm/m level when moving between 30% and 70%. Variations within this range are quite usual in office environments during the power on/off cycles of air conditioning.

If not adjusted automatically by a direct measurement system like OMAS, media advance drifts at those levels will require either regular customer intervention to restore the original image quality or a thorough system characterization capable to predict the advance deviation under every possible circumstance.

Over time new applications have been identified and successfully implemented for OMAS beyond its original design intent. They range from the real time compensation of paper skew to the detection of registration marks in dual side printing workflows in HP's industrial printers, which profit from the sensor monitoring the backside surface of the media from inside the printer platen.

The actual performance of the sensor is limited by:

1. The maximum frame rate of the current CMOS sensor + FPGA is 250fps. This is a hard limit for media advance speed to 30 inch/s.
2. A minimum level of texture is required within the detected images to ensure the reliability and accuracy of the correlation algorithm (this corresponds approximately with a roughness of R_a=0.1µm in the back side of the media).

While the first limitation is clearly practical, the second is direct consequence of the grazing illumination design and could be overcome by a specular implementation of the lighting system and optics.

Summary and Conclusions

OMAS is a sensor developed by HP to enable Large Format Printers to meet the demand of higher accurate media advance at higher printer throughput.

The sensor solution is a highly evolved combination of a hardware (optics and electronics) and firmware (control and algorithms) that provides the needed precision at the required cost and form factor. The optoelectronics features a custom image sensor, high precision optics, flash LED illumination system and a processing board with control FPGA and DSP processor. Regarding the algorithm, two processes enable Optical Navigation over long distances. First, the acquisition by means of two independent windows on a single sensor well separated in the media advance direction. And second, a real time implementation with sub-pixel accuracy requires a two-step correlation algorithm with a rough global search first and a subsequent local refinement.

As a result, direct media advance measurement with OMAS has an unprecedented precision and is almost insensitive to many conditions that affected previous systems (harmonic variations in the media drive system, variation of the back tension with the roll diameter, changes in media thickness, stiffness, and coefficient of friction, paper dust accumulated in the print platen, etc.). This robustness means accurate line lengths and consistent quality in images, area fills, and line drawings over a wide range of temperature and humidity conditions, and it is crucial for dependable performance over the life of the printers in production printing environments.

The use of OMAS beyond media advance feedback systems is being explored in new developments. As a media movement sensor in assembly line tooling for lower end printers or part of an in-system calibration equipment in high end industrial-presses. Although not yet fully explored, authors believe other applications for a sensor like OMAS are possible beyond printing systems.

References

[1] US Patent 5,729,008 "Method and device for tracking relative movement by correlating signals from an array of photoelements" Travis N. Blalock et al (1998).

[2] US Patent 5,149,980 "Substrate advance measurement system using cross-correlation of light sensor array signals" John Ertel et al (1992).

[3] US Patent 6,433,780 "Seeing eye mouse for a computer system" Gary Gordon et al (2002).

[4] C.D. Kuglin and D.C. Hines, The Phase Correlation Image Alignment Method, Proc. *Int. Conf. Cybernetics Society*, pg. 163 (1975)

Author Biography

Marc Casaldàliga received his BS in Physics from the "Universitat Autònoma de Barcelona" (1997) and the M Sc in Computational Physics in "Institut de Física d'Altes Energies" (Barcelona, 1999). He joined then the MAGIC Telescope Collaboration, which develops and runs a gamma ray Telescope in the Canary Islands, Spain.
Since 2002 he has worked in R&D division in HP Large Format Printers in Barcelona. From the beginning he has been involved in the investigation and development of OMAS and more recently he is also working in the writing system development on HP LX series printers.

Sascha de Peña. Physicist. Master in Business Administration (MBA, ESADE, 2004). He received his BS in Physical Sciences from the Technische Universität München (1993) and his Ph D in Plasma Physics (1997) conducting research at the Max-Planck-Institute for Plasma Physics (IPP) concerned with the investigation of the physical basis of a fusion power plant. Currently,he is Senior Technologist and R&D Chief Engineer at HP's Imaging and Printing Group, responsible for the technical direction of the new large format Z series printer and in charge of the evaluation and development of technologies for additive manufacturing.