Variable Data Cylinder Printing

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Abstract

There is a need for a fast digital printing technology that can be used in-line on an analogue printing press, initially for Variable Data on Press (VDOP) applications. Inkski Ltd has been developing a novel drop on demand technology, 'Light Initiated Liquid Offset' (LILO) based on the forming of ink drops on a rapidly rotating cylinder. This paper looks at the principles governing the LILO technology and the results achieved from this development, also outlining the technical challenges remaining. The performance characteristics of an offset lithography equivalent printing process are identified and compared to LILO and other digital printing approaches. The conclusion is that unmodified none of these approaches currently have the potential to achieve offset equivalent printing. We briefly introduce an evolution of the LILO technology, which may have the potential to provide an offset equivalent digital printing process.

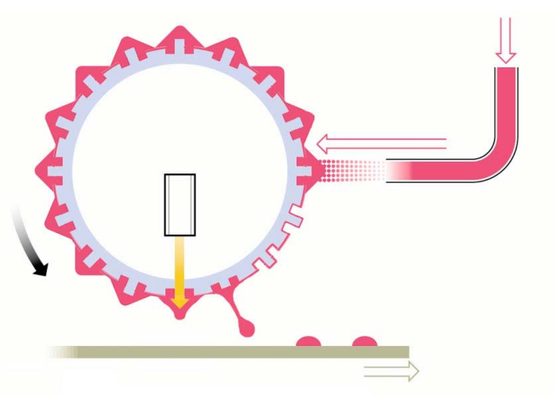
Introduction

Inkski has been developing a novel digital printing technology. The initial aim is to provide a variable data capability in-line on a conventional analogue press. With the ultimate goal of allowing digital printing that is equivalent to offset lithography in quality, speed and substrate flexibility.

This paper considers the limits of Inkski's 'Light Initiated Liquid Offset' (LILO) technology, comparing this with other digital printing technologies and the performance requirements of offset equivalent printing.

LILO Principle

LILO works by allowing pendant ink drops to form on the surface of a transparent cylinder. As the 'jetting' cylinder rotates, laser pulses from inside the cylinder trigger drops to be ejected from the surface of the cylinder onto a substrate.



Schematic showing how ink is sprayed onto the LILO jetting cylinder forming drops at the structured cylinder surface. Laser pulses from inside the cylinder eject drops onto a moving substrate.

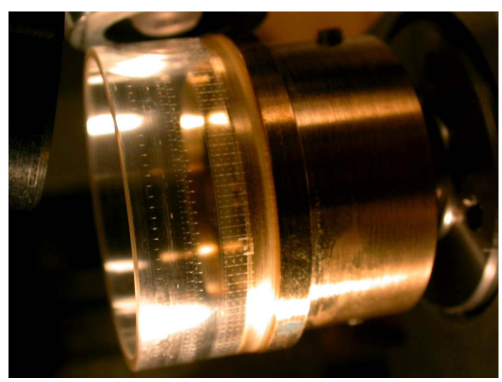
Conventional DOD inkjet faces a physical limitation on the maximum drop ejection frequency per nozzle. This limit is a consequence of liquid ink behavior, in particular the characteristic relationship between inertia and surface tension that forms drops and restores the nozzle meniscus. For inviscid liquids this characteristic time constant of the liquid (the time frame within which a fluid reacts mechanically to its own surface tension) is a function of the Rayleigh time formula $\tau_R = \sqrt{(\rho R^3/\sigma)}$, where **R** is the radius of curvature of the liquid system, ρ the density of the liquid and σ the surface tension[1][2].

For commonly required ink rheologies and drop volumes the above intrinsic property of fluids seems to limit individual DOD inkjet nozzles to ejecting drops at about 20 kHz. The nozzle actuators themselves may react faster than this to allow multiple pulses of liquid to be accumulated into a single drop, i.e. for multi-level printing, but the drop repetition rates are still limited by the fluid mechanics of the system.

LILO allows the drop forming process to be de-coupled from the ejection frequency. Because new drops continually arrive at the ejection trigger point on the cylinder surface, there is no need to wait for one drop to be fully ejected and the meniscus re-formed before ejecting the next drop.

We have demonstrated that by patterning a cylinder surface with 3D structures a high density array of available ink drops can be formed from a continuous film applied to the cylinder. This allows the per channel ejection frequency from the cylinder to be as high as 500 kHz, about 25 times the conventional DOD limit.

As the LILO jetting cylinder rotates, any excess heat at the ejection point is immediately removed. This allows LILO to overcome the thermal dissipation limit sometimes encountered with conventional fixed position inkjet nozzles.



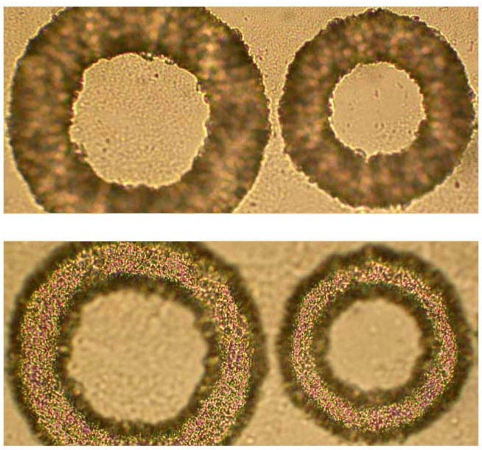
Experimental fused silica LILO jetting cylinder with 3D structures formed on the outer surface.

LILO Challenges

In order to deliver a commercial system based on LILO technology there are some significant challenges which would need to be overcome.

Directional Variance

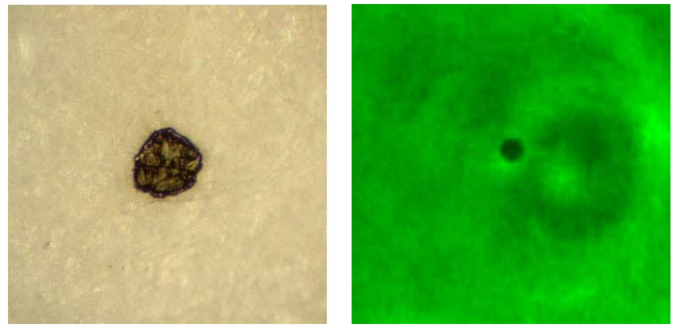
With conventional inkjet the inertial confinement afforded by an enclosing nozzle is a great advantage in creating a highly directional drop ejection. With LILO we have found it hard to achieve good directionality without employing some kind of nozzle like structure (e.g. a well) on the surface of the jetting cylinder. Such 3D microstructures are difficult and expensive to manufacture in transparent cylinders. For research purposes we have developed a technique using incremental picosecond laser ablation onto a fused silica cylinder, to form arbitrary 3D surface structures.



3D annular well structures formed on the surface of a fused silica cylinder using 355 nm picosecond laser ablation. The top image is focused on the top of the cylinder surface, the bottom image is focused on the base of the wells. The annular structure on the right is 120 um across and approximately 15 um deep.

Energy budget

A thermal bubble ejection from a cylinder surface cavity can be used to achieve the desired drop ejection directionality. However this requires a high input energy. We find the required pulsed light input energy is in the range 0.5-2 uJ per drop, corresponding to a photon to kinetic energy conversion efficiency of around 0.1%. Input wall-plug electrical energy to coherent photon energy conversion is typically less than 10% giving an overall kinetic energy conversion efficiency of less than 0.01%. This would create significant thermal management issues for full scale systems that may require several billion drops per second. This efficiency is in line with the input to kinetic energy conversion efficiency for thermal DOD which is considered to be about 0.02%[3], but relatively higher repetition rates create a problem of heat dissipation at the laser energy source.



The right-hand image above shows an approximately 10 pL drop of ink ejected by a 2 uJ laser pulse from inside a spinning LILO jetting cylinder. The image was taken about 10 us after ejection from a 3D structure (hidden beneath the ink layer). The left-hand image shows the same type of drop captured from the cylinder onto a paper substrate.

It would be preferable to use a lower energy actuator mechanism, e.g. triggering ejection by heat-driven Marangoni forces. The Kodak Stream technology makes use of the Marangoni force principle to efficiently modulate a continuous free jet[4]. However we have found that the less symmetrical surface attachment forces associated with drops on a LILO cylinder (compared to a free liquid jet) make this mode of ejection hard to achieve reliably, and the relatively long drop evolution time contributes to time induced variability.

Photon Costs

Collimated light sources are relatively expensive to manufacture. Currently LILO requires rapid modulation of pulsed energies around 1uJ per pulse. Appropriate photonic sources cost at least 100 times more than energy equivalent thermal microheaters. For large systems with perhaps 100,000 actuators this would be a significant capital cost burden.

Offset Comparison

Having identified offset equivalent printing as our ultimate objective it is useful to explore the characteristics that make 'planographic offset lithography' so effective for high quality, long run printing. Similar characteristics also tend to apply to other analogue printing techniques such as flexography and gravure.

Minimum dot

Offset printing has relatively poor minimum dot size characteristics. The smallest dot that can be held on a typical offset press is only in the region of 25um diameter and on this scale dots may be quite variable in density and extent. Visually this does not usually cause a problem though it can show up as color instability in lighter halftones. In general digital printing technologies tend to have much better control over the density and size of the minimum dot.

Edge Accuracy

This is where offset printing usually wins over digital printing quality. Even though offset can't generally reproduce lines thinner than about 25um, offset is able to reliably vary the relative position of edges to 10um or less.

The eye is highly sensitive to the interpolated position and direction of edges[5]. 'Vision' can be considered an emergent property of many levels of visual processing, and in particular the interpolated sharpness, direction and relative position of edges are key cues to the image recognition process[6]. This explains why an offset printer will make plates at 2400 dpi even though their press may not hold a 20um (1200 dpi) dot. Ultimately it is edge fidelity which gives offset printing its characteristic quality.

Halftone Screens

Halftone rendition is more than a matter of equivalent lines-per-inch or gray-level resolution. As those who developed stochastic screening found out, commercial printers are concerned with a range of qualitative issues: described by words like 'punch' or 'grain'. Typically a conventional halftone screen imposes a strong spatial signal at 150 or 200 lpi. This makes the image appear smoother and therefore the apparent quality of the substrate and printing better than it should be. Therefore 'photographic' (un-screened) rendition may not always be preferable to a conventional halftone screen, and where it is (e.g. for actual photographs) the substrate usually needs to be exceptionally flat and noise free. Conventional screens allow higher perceived quality on lower quality stock thus reducing the required cost of the substrate.

Even using good super-cell halftone algorithms (which distribute the required halftone dot variation between neighboring halftone cells) good quality conventional halftoning at 150 lpi typically requires at least 1200 dpi and ideally 1600 dpi plate resolution. For 200 lpi, 1600 dpi to 2400 dpi is preferred. For higher lpi's and non super-cell halftones plate resolutions up to 4000 dpi are used for best quality.

Equivalent Speed

Typically a sheet-fed offset press might operate at 5 m/s and an offset web press at around 10 m/s. Taking 1200 dpi as the minimum resolution and 2400 dpi as the maximum (see screens above) this implies offset printing is equivalent to a per channel binary dot frequency of 250 kHz to 1 MHz.

Ink quality

Viscous offset inks allow a wider range of pigments which tend to have superior color filtering properties, especially compared with dry toners which have to be physically hard (and therefore non-transmissive) particles to avoid disintegration.

Substrate cost

Offset printing contributes significantly to keeping the substrate cost as low as possible by using conventional halftone screens to mask high frequency noise, and by allowing low-penetration inks to be used which reduces show-through and thus allows relatively thinner and more absorbent stock to be used.

Ink cost

Offset printing allows large pigment particles and particle agglomerations to be printed which tend to be cheaper and easier to handle compared with typical digital printing ink dispersions and liquid toners. Low penetration into the substrate also means less pigment is required to achieve the same color density.

Flexibility

The ability to print with high viscosity liquid inks allows more flexibility in the inks and solvent systems, allowing metallics and other difficult to print inks. This in turn leads to greater flexibility in the choice of substrates, coatings and ink curing systems.

Recycling

The large pigment particle size and low penetration of offset ink into the substrate make it easy to separate typical offset pigments from paper during recycling.

Multi-level image rendition

Using a variable drop size significantly improves image resolution on a low resolution output device. However multi-level rendering does nothing to mask the noise of the substrate or to give images the 'smooth' halftone look that some people like. A hybrid approach can sometimes be used combining a pseudo-conventional screen with multi-level output, but this still needs a relatively high spatial resolution to avoid inter-screen moiré effects.

Multi-level font rendition

This greatly increases intelligibility at low resolutions[7] but at the cost of making edges look 'soft', which unfortunately our visual system may interpret as 'out of focus'. Given the choice between high spatial edge resolution and lower resolution anti-aliased rendition of fonts people generally prefer the look of higher spatial resolution because edges look crisp. Ultimately 'sharpness-of-edge' is a basic property of an image and if this is compromised it will reduce the perceived image quality.

With the above multi-level rendition points in mind, it is reasonable in the context of this analysis to characterize 'offset quality equivalence' as being a binary process, as opposed to photographic quality rendering which can be multi-level.

Offset equivalent digital printing

We can now hazard a definition for 'offset equivalent' digital printing:

- **Speed**: a minimum 250 kHz per-channel down-web dot frequency
- **Resolution**: at least 1200 dpi resolution
- **Ink:** high viscosity, e.g. >50 cps
- **Pigment size**: large particles, e.g. to 1 um

If we accept this definition of offset equivalence then there is currently no available offset equivalent digital printing technology. Which is not to say that current digital printing technologies do not have great utility and huge markets. But it does perhaps imply that, unmodified, current technologies will not readily replace offset printing for high quality, high volume printing.

Based on the above definition and inherent physical constraints we can make a comparison of the capabilities of digital printing technologies with offset printing.

Offset to digital physical limitations comparison

	Speed (250 kHz)	Resolution (1200 dpi)	Viscosity (>50 cps)	Particle (to 1 um)
DOD-Inkjet	N	Y	N	N
CIJ-inkjet	Y	N	Y	N
Liquid toner	N	Y/N	Y	Y
Dry toner	Y	Y	N	Y
LILO	Y	Y	N	N

Offset digital potential performance capabilities

	Quality	Speed	Cost	Flexible	Recycle
DOD-Inkjet	Y	N	N	N	N
CIJ-inkjet	N	Y	N	Y	N
Liquid toner	Y/N	N	N	N	Y
Dry toner	N	Y	Y	N	Y
LILO	Y	Y	N	N	N

The projected advantage of LILO over inkjet for the offset application is speed. However LILO would still face the same limitations as inkjet in ink viscosity and pigment particle size. Therefore while LILO may plausibly attain the quality and the speed of offset it cannot of itself easily achieve the low cost, flexibility and recycling compatibility associated with offset printing.

Beyond LILO

LILO has enabled us to explore a new set of parameters for digital printing and is now allowing us to develop approaches related to LILO with further improved characteristics. We know that the ideal technology would require less drop ejection energy than LILO and also handle high viscosity inks containing large pigment particles.

Inkski is currently developing an evolution of the LILO technology, Electro Initiated Liquid Offset (EILO) that promises to meet the requirements of offset equivalent digital printing.

EILO

Inkski is not yet able to disclose technical details of the EILO technology, however the following points can be made:

- As with LILO, drops are formed initially on a rotating cylinder, allowing EILO to separate the time required to select ink for transfer from the time required to complete the ink transfer.
- With EILO the energy required for ink transfer is provided over the length of the transfer process rather just at the beginning. This allows higher viscosity inks and greater transfer energy efficiency.
- EILO uses electrons rather than collimated photons as the transfer trigger and therefore provides for a low cost per channel actuator.

Conclusion

The work that has gone into LILO has allowed Inkski to explore the opportunities and challenges for very high speed digital printing. This in turn has led to the evolution of EILO, a new method for digital printing.

The large installed base of analogue printing presses and related handling systems creates an opportunity for compatible print technology. Inkski aims to provide OEMs with access to a digital technology that can be incorporated within existing press formats.

Inkski is now developing EILO towards realizing a Variable Data On Press (VDOP) printing unit for incorporation on an analogue press, and this development may ultimately lead to the development of an offset equivalent digital press.

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Author Biography

Daniel Hall founded Inkski Ltd in 2004 and leads the development of the company. In the early 1990s Daniel developed innovative technologies for Harlequin Ltd, including HDS, a stochastic FM screening technology. In 1995 he co-founded Advanced Rendering Technology Ltd which developed the first parallel ray tracing graphics processor. Daniel has a PhD from the University of Cambridge Computer Laboratory in image processing and pattern recognition.