Industrial inkjet technology

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Scope of talk

- how ink-jet printing works and some research challenges
- examples of our recent research
Printed processes

- Conventional printing
  - all processes use a durable matrix/plate which is used to transfer ink to a substrate
  - involves contact with substrate
  - ideal for producing large numbers of identical copies

- Ink-jet printing
  - ink is delivered in individual droplets to the substrate
  - non-contact process
  - can print a sequence of identical or completely different products
  - completely flexible, digital process
Key features of inkjet printing

It is a **digital** process – the location of each droplet of ink can be accurately positioned on a grid, under computer control. Patterns can be varied immediately between or even within individual products.

It is a **non-contact** method and so can be used to print on surfaces which are not flat, and also for fragile surfaces.

A **wide range of materials** can be deposited. The only limitation is that they must be in liquid form at the time of printing.
Maturity of technology

Date


Marking & coding
Consumer and SOHO printing
Commercial printing
Manufacturing/Direct writing
The Cambridge cluster

[extended from Garnsey et al. 2009]
Drop-on-demand printing: principles

- Each drop (typically 20 – 50 µm diameter) is produced in response to an electrical signal to an actuator in the nozzle chamber.
- The printhead contains a large number (hundreds) of separately addressable nozzles.
- There are two common types of actuator: thermal and piezo-electric.
Drop-on-demand: industrial piezoelectric printhead

- Example of a modern drop-on-demand industrial printhead:
- 1000 nozzles over 70 mm length i.e. 70 µm spacing
- $\sim 10^4$ drops per second emitted from each nozzle
- variable drop volume 6-42 pL (= 22-43 µm diameter)
The journey from nozzle to substrate

**bulk ink**

**jet**

**drop**

**product**

**dominant physical effects**
- acoustics
- viscosity, inertia
- capillarity
- electrostatics
- aerodynamics

**dominant chemical effects**
- solvent/solute/particle interactions
- nozzle wetting
- solvent/solute/particle/surface interactions
- inertia, viscosity, capillarity
- drying/curing
Timescales in inkjet printing

- CIJ: 1 ns
- DoD: 1 µs
- Drop formation: 1 ms
- Drop impact: 1 s
- Head flooding: 10^3 s

- Characteristic polymer times
- Characteristic viscous time
- Drop travels own diameter
- Drop formation time for drop to travel to surface
- Impact-related spreading
- Capillary spreading
- Curing/drying time
- Surfactants
- Collapsing
- Recovery
Jet imaging

- Flash controller
- Printhead controller
- CCD camera and lens
- 20 ns flash

Fully automated image capture and delay variation

Alternative mode: long duration light source and high speed framing camera
Single-flash image: 20 ns duration

400 µm
Pseudo-sequence of images
Modelling of fluid flow in jet formation

Lagrangian FE model for viscoelastic flows (multiple modes) with inertia & free surfaces

Mesh adaptivity to handle thin filaments & droplet break-off

(Harlen, Yarlanki and Morrison, University of Leeds)
Breakup of liquid filaments

What controls whether a thin filament of liquid separates into two or more droplets or condenses lengthwise to form a single drop?

Breakup of liquid filaments

Breakup is controlled by the initial dimensions of the filament and the liquid properties: density, viscosity, and surface tension.

\[ Oh = \frac{\eta}{\sqrt{\rho \sigma R_0}} \]
High-speed holography for ultra-precise measurements of drop size and position

Typical accuracy in measurement of position (x, y, z) and drop radius $\pm 0.3 \mu m$

[Martin et al., Proc. NIP27 (2011) 620-623]
CADET – a new method for generating small drops

[Castrejon-Pita et al., Rev Sci Inst, 83 (2012) 115105]
Electrohydrodynamic high-resolution deposition

continuous (electro-spinning)

intermittent (electro-printing)
Elastic effects due to polymers in ink

[ Hoath et al., J. Rheology, 56 (2012) 1109]
Drop impact

What happens when a liquid drop hits a surface depends on the relative effects of inertia, viscous and surface tension forces – which can be described by the Reynolds and Weber numbers:

\[ Re = \frac{\rho V D}{\mu} \quad We = \frac{\rho V^2 D}{\sigma} \]

Splashing does not occur for typical drop-on-demand conditions – it is favoured by a larger drop, higher impact speed, lower surface tension, lower viscosity or a rough substrate.
Modelling of drop impact: heterogeneous surface

Water drop, 2 mm diameter, 1 m/s
Numerical model based on level set method:
linear viscous fluid with surface tension and gravity
Simulation: Kensuke Yokoi
Experiment: Damien Vadillo, CU Dept of Chemical Engineering
Effect of print frequency/spacing on drop merging

Print frequency: 398 Hz
Effect of print frequency/spacing on drop merging

Print frequency: 429 Hz
Aerodynamic effects in printing on a moving substrate

Individual frames from high speed framing camera (41,000 fps, 20 µs exposure time)

Side view of 20 nozzles

printhead

substrate motion

5 mm
Aerodynamic effects in printing on a moving substrate

Laser and optics

Moving substrate

printhead

Smoke (seeding particles for PIV)

region of interest
Aerodynamic effects in printing on a moving substrate
Applications of inkjet in manufacturing

- Additive manufacturing: polymers
- Fabrics, wallpapers, laminates
- Passive electronic components
- Additive manufacturing: metals, ceramics
- Active electronic components
- Optics: lenses, waveguides
- Biomedical devices: lab-on-a-chip, diagnostic arrays
- Sensors: acoustic, thermal, mechanical, optical, bio
- Smart materials: integrated sensors, transducers
- Tissue synthesis: artificial skin, bone, organs
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Our expertise and research interests

- high speed, high resolution optical imaging by conventional and holographic methods
- diagnostic techniques for external and internal liquid flows including LDV and PIV
- generation and behaviour of liquid jets and drops, from both continuous and drop-on-demand inkjets
- fundamental fluid mechanical phenomena in jets and drops
- drop impact on non-porous and porous surfaces
- wetting and dewetting
- liquid penetration into porous and fibrous media
- drop merging and mixing
- effects of complex rheology
- inkjet as a tool for manufacturing, including additive manufacturing, microfluidics and bio-applications
Inkjet Interest Group

6-monthly evening meetings - presentations plus dinner

Next meeting: 28 July 2015

We are always glad to discuss opportunities for collaboration

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Further information:
www.ifm.eng.cam.ac.uk/research/irc/