Direct-to-Shape Printing of Complex Objects

Phil Collins, Director – Advanced R&D
Global Inkjet Systems Ltd

Inkjet Interest Group – 23rd January 2019
GIS – Company Overview

- Leading provider of technology solutions to industrial inkjet systems builders
- Supported printhead manufacturers
  - Fujifilm Dimatix, Konica Minolta, Kyocera, Ricoh, SII, Toshiba Tec, Xaar
- Founded November 2006
  - Privately owned
- Based in Cambridge, UK
  - Technical support in UK, China and Japan
- Employees 70+
- Patent protected technology
- Supplier & partner to over 130 customers worldwide
GIS – Products

**DFE**
Atlas® User Interface

**Machine Control**
Atlas® Server

**Print Controllers**
Drive Electronics

**IDS**
Ink Delivery Systems

**Used in broad range of applications** – textiles, labels, security printing, décor, spot varnish, product decoration, corrugated, ceramics, functional coatings, materials deposition, 3D, robotics and more
Agenda

- **Challenges**
  - What are the problems?
- **Tubes, cones & tubs**
  - Widely used, so experience exists
  - Assumptions of 2D printing start to break down
- **More complex shapes**
  - A generic approach, applied to a sphere
  - Some new challenges
  - From concept to reality
Tubes

• **Well established/well understood technology**
  - Fixed radius of curvature
  - Cylinder unwraps to a rectangle or square

• **But as print speed is increased, and/or radius of curvature decreased**
  - Throw distances vary
  - Flight time differences become significant for multi-column print heads

Image & animation source: GIS
Cones

- Cones or cone sections are useful for many applications
  - Unfolds to an arced rectangle / section of a circle
  - Corrections are relatively simple, provided heads are narrow and mounted symmetrically

- Challenges
  - Nozzle alignment
  - Density correction
  - Dot gain management
  - Avoid screening artefacts

Image & animation source: GIS
Tubs

- Mixture of cone sections and flat surfaces
- Necessary corrections change during the print
  - Often from pixel to pixel
- Print system is more complex
  - No longer rotating about a single axis
  - Transport design may require a synthetic encoder
# Challenges

<table>
<thead>
<tr>
<th></th>
<th>Flat Surfaces</th>
<th>Curved Surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density Correction</strong></td>
<td><img src="image1.png" alt="Density Correction Flat" /></td>
<td><img src="image2.png" alt="Density Correction Curved" /></td>
</tr>
<tr>
<td><strong>Throw Distance &amp; Flight Time</strong></td>
<td><img src="image3.png" alt="Throw Distance &amp; Flight Time Flat" /></td>
<td><img src="image4.png" alt="Throw Distance &amp; Flight Time Curved" /></td>
</tr>
<tr>
<td><strong>Nozzle Alignment &amp; Interleaving</strong></td>
<td><img src="image5.png" alt="Nozzle Alignment &amp; Interleaving Flat" /></td>
<td><img src="image6.png" alt="Nozzle Alignment &amp; Interleaving Curved" /></td>
</tr>
<tr>
<td><strong>Screening</strong></td>
<td><img src="image7.png" alt="Screening Flat" /></td>
<td><img src="image8.png" alt="Screening Curved" /></td>
</tr>
<tr>
<td><strong>Transport &amp; Encoder Configuration</strong></td>
<td><img src="image9.png" alt="Transport &amp; Encoder Configuration Flat" /></td>
<td><img src="image10.png" alt="Transport &amp; Encoder Configuration Curved" /></td>
</tr>
</tbody>
</table>
Agenda

• Challenges
  • What are the problems?

• Tubes, cones & tubs
  • Widely used, so experience exists
  • Assumptions of 2D printing start to break down

• More complex shapes
  • A generic approach, applied to a sphere
  • Some new challenges
  • From concept to reality

Direct-to-Shape Printing of Complex Objects
More Complex Shapes

- **Strong demand in the market – particularly industrial**
  - Automotive parts; industrial components; aerospace; and much more....
  - Many projects underway – most long term and confidential
- **Automotive examples - using Heidelberg Omnifire 250/1000**
  - Mercedes Smart cars
    - Customisation of ventilation nozzles, instrument bezels
  - Borbet
    - Alloy rims

Images from InPrint Blog – review of IAA 2017, Frankfurt Motor Show
Generic Curved Surface Workflow

- Creation Tools
- Import Mesh & Texture
- Swathe Decomposition
- Transport Control
- Colour Separation
- Unwrap
- Density Correction & Screening
- Print Control

Swathe paths
Wrapping a Sphere

- Many tools available for wrapping
  - Well established technologies from gaming, augmented reality industries, etc.
  - Many different ways to wrap, edit directly on to 3D surfaces
Unwrapping a Sphere

• “Unwrap” the image and design a print path
  • Taking into account the constraints of the object to be printed, inkjet printhead, capability of the robot
  • Currently we do this manually, which is appropriate for most manufacturing applications, but there is research towards automation
Where Can We Print?

At printhead scale and below: convex or near-convex shapes

Convex
\[ r \geq w \]

Near-convex
\[ h < h_{\text{max}} \]
Where Can We Print?

At printhead scale and below: convex or near-convex shapes

- **Convex**
  - \( r \approx w \)

- **Near-convex**
  - \( h < h_{\text{max}} \)
Where Can We Print?

At larger scales: anywhere we can reach
e.g. in-mold decoration (IMD)
Positioning Accuracy

Industrial robots have excellent accuracy for many industrial applications ...

... but printing requirements are tight

- Typical industrial robots have absolute accuracy of 200-500 µm
- Inkjet printing requirements are typically 10x finer
- Robot repeatability is better than absolute accuracy, so calibration is possible
# Transport Mechanisms

<table>
<thead>
<tr>
<th>Advantages</th>
<th>General Purpose Robots</th>
<th>Custom Mechatronics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Available off-the-shelf</td>
<td>• Specific to application</td>
</tr>
<tr>
<td></td>
<td>• Many specifications</td>
<td>• Implementation efficiency</td>
</tr>
<tr>
<td></td>
<td>• Well supported</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
<th>General Purpose Robots</th>
<th>Custom Mechatronics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Positioning accuracy</td>
<td>• One-off design, build and debug costs</td>
</tr>
<tr>
<td></td>
<td>• Under utilisation of standard feature sets</td>
<td>• Timescale</td>
</tr>
<tr>
<td></td>
<td>• Encoders not included</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suitability</th>
<th>General Purpose Robots</th>
<th>Custom Mechatronics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fast development, short run systems that fit available specifications</td>
<td>Longer production runs Systems with special requirements</td>
</tr>
</tbody>
</table>
Encoders

- **Very useful when printing on flat or regular curved surfaces**
  - Jetting precision 1 µm (<5% pixel pitch @ 1200 dpi) possible
  - Harder to apply to complex print paths
- **Not standard on industrial 6-axis robots**
  - But can be added
- **Hybrid techniques**
  - Combine robot handling for shape orientation with linear transport plus encoder
  - Synthetic encoders: combine multiple encoder inputs into one

Image source: Renishaw
Shape Accuracy

All manufactured objects have tolerances
- E.g. Polypropylene sphere
- Inexpensive consumer product

Nominal: 75 mm radius

Structural errors
Assembly of two hemispheres
1-1.5 mm

Precision errors
Limitations of process
~0.25 mm
• Stitching is a key area where inaccuracies will show
  • Positioning errors cause gaps or overlaps, familiar from 2D printing

• Careful control is required of multiple factors:
  • Accuracy of transport, especially robots near to singularities
  • Print synchronisation
  • Variation of the target shape from nominal dimensions
Shape Variation Compensation

- **Measure the target shape accurately**
  - Mechanical profile gauges
    - Adequate, but rather slow
    - Contact with target shape may be a problem
  - Laser triangulation sensors
    - Resolutions down to ~1 µm, sample rates 1-100kHz
    - Non-contact
- **Apply measurements as corrections to the mesh model**
  - For per unit variations this can be done as a late stage correction
  - Output adjusted swathe data
From Concept to Reality

• Starting with a sphere
• Using a robot to position the shape under the printheads
• We built a test print rig
Sphere Printer – The Movie
From Concept to Reality

Result: a printed polypropylene spheroid

- CMYK 1200 dpi
- Latitude swathes, 18⁰ high
- 300dpi native; x 4 interleave
Key Points to Take Away

- Inkjet printing of complex irregular shapes is possible today
- Precision positioning is vital, and more complex than for 2D
- Industrial robots are very useful, but not the whole solution
Thank you – Any Questions?

**Phil Collins**, Director – Advanced R&D
phil.collins@globalinkjetsystems.com

**Global Inkjet Systems Limited**
Edinburgh House
St Johns Innovation Park
Cowley Road
Cambridge CB4 0DS
UK

Tel: +44 (0)1223 733 733
Web: www.globalinkjetsystems.com

Technical support offices in UK, Japan and China