Direct-to-Shape Printing of Complex Objects

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Global Inkjet Systems Ltd

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GIS – Company Overview

- Leading provider of technology solutions to industrial inkjet systems builders
- Supported printhead manufacturers
  - Fujifilm Dimatix, Konica Minolta, Kyocera, Ricoh, 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
<table>
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<tr>
<th>Challenges</th>
<th>Flat Surfaces</th>
<th>Curved Surfaces</th>
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<tr>
<td>Density Correction</td>
<td><img src="image-1" alt="Density Correction Flat" /></td>
<td><img src="image-2" alt="Density Correction Curved" /></td>
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<tr>
<td>Throw Distance &amp; Flight Time</td>
<td><img src="image-3" alt="Throw Distance Curved" /></td>
<td><img src="image-4" alt="Throw Distance Flat" /></td>
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<td>Nozzle Alignment &amp; Interleaving</td>
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<td>Screening</td>
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<td>Transport &amp; Encoder Configuration</td>
<td><img src="image-9" alt="Transport &amp; Encoder Curved" /></td>
<td><img src="image-10" alt="Transport &amp; Encoder Flat" /></td>
</tr>
</tbody>
</table>
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
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
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
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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

Swathe paths

Transport Control

Colour Separation

Unwrap

Density Correction & Screening

Print Control
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
Simulated Print Sequence
Simulated Print Sequence
Simulated Print Sequence
Simulated Print Sequence
Simulated Print Sequence
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 printhead scale and below: convex or near-convex shapes

Convex: $r \geq w$

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>
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</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
<th>General Purpose Robots</th>
<th>Custom Mechatronics</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>• Positioning accuracy</td>
<td>• One-off design, build and debug costs</td>
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<td></td>
<td>• Under utilisation of standard feature sets</td>
<td>• Timescale</td>
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<tr>
<td></td>
<td>• Encoders not included</td>
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</tbody>
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<th>Suitability</th>
<th>General Purpose Robots</th>
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<td></td>
<td>Fast development, short run systems that fit available specifications</td>
<td>Longer production runs Systems with special requirements</td>
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</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
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
Shape Accuracy 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 delta
  - Output adjusted swathe data
Stitching

• 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

Image source: GIS
From Concept to Reality

- Starting with a sphere
- Using a robot to position the shape under the printheads
- We built a test print rig
Apply the Workflow

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

Robot Controller

Image source: GIS
Result: a printed polypropylene spheroid

- CMYK 1200 dpi
- Latitude swathes, 18° 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?

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