Digital System Integration in the Context of Industry 4.0

Digital Manufacturing

Dr. Steffen G. Scholz

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Overview

- Introduction
- Industry 4.0
- Flexible manufacturing
- Digital printing materials
- Tailored applications
- Conclusion
Introduction

- Embedded System enabling CPS and CPPS

Source: University Darmstadt
Introduction

Convergence of information and operational technologies

Digital Manufacturing

- Computer assisted design
- Complex system simulation
- Additive manufacturing
- Cloud data storage
- Big data
- Connected objects
- Numerical Controlled Machine
- System Integration
INDUSTRY 4.0
as part of the Internet of thing
The Internet of Thing

"We define the internet of things as sensors and actuators connected by networks to computing systems. These systems can monitor or manage the health and actions of connected objects and machines. Connected sensors can also monitor the natural worlds, people and animals."

McKinsey Global Institut
The Mission

A world always more connected

1995
15 million people with internet access

1997
6 million object with internet access

2020
7 billion with internet access

2020
50 billion objects connected to Internet

Source: Bosch
Self organised and distributed artificial intelligence

Fast and automatic network integration, highly flexible

Open standards

Virtual real-time image

Digital integrated life-cycle-management

Safe and secure added-value networks

Humans as actors and in the centre
New paradigm

How to compute the enormous quantity of data coming from sensors and convert it in value creation?
Flexible Manufacturing Example: Project SMARTLAM
Flexible Manufacturing

The consortium

- Project Duration: 2012/10-2016/01
- Project Number: 314580
- Project Volume: 4.1 mio Euro
- Req. EC contribution: ca. 3 mio Euro

- 4 R&D partners
- 2 Technology partners
- 2 Reference customers

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Institute for Applied Computer Science
The ambitious vision

Stacking of thin polymer films, each with specific properties utilizing advanced film material and surface properties for batteries, wiring, sensors and fluidics (structures and printed components)
Flexible Manufacturing

Targets & topics

- Capability to rapidly produce 3D mechatronic micro systems
- Increased flexibility and scalability of processes
- Reduced energy consumption
- Reduction of development and sale up time
- Product quality improvement
- Waste reduction and reduced impact on the environment

3D-I Modelling & design approach
3D-I compatible production platform
SMARTLAM adaptive control and vision inspection

R&D Topics

Project targets

07.04.2017
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Institute for Applied Computer Science
Flexible Manufacturing

Modularity concept

SMARTLAM 6 modules
- Lamination
- Laser welding
- Laser structuring
- Printing module (aerosoljet printing)
- Assembly
- Inspection
Flexible Manufacturing

Project overview

SL – Flexible scalable Manufacturing Concept (3D-I)

Modular Equipment concept

Manufacturing Hardware

Production Management

ERP / costs
Process Simulation
Control (forte)

Application Management

Design
Simulation

Modular Application concept

Manufacturing Software

Demonstrator Development

Application Building blocks

Features
Functional Elements

Cells
Modules

Linkage between Process (chains) and features / functional elements
Application 1 – LED lighting

- Light source embedded into surgical instrument
- Product includes 1. planar light-guide LED chip source, electronic control, switch and power source
- Sealed and to have high hermiticity for medical accreditation.
- Custom size and light specifications for different surgical procedures
- Specification will evolve over time
- Disposable
- Cost/volume critical – e.g. Veterinary market

Source: DLED
Additive Manufacturing in the context of Industry 4.0
Additive Manufacturing
Definition & Timeline

Definition of AM:

„The process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining“¹

Typical technologies:

- Laser/Light Polymerization (e.g. stereolithography)
- Laser Melting (e.g. selective laser sintering, selective laser melting)
- Extrusion processes
  (e.g. fused filament fabrication, fused deposition modeling)
- Material jetting (e.g. inkjet printing or multijet modelling)
- Adhesive based processes (e.g. laminated object manufacturing)
- Electron beam manufacturing (EBM)

Additive Manufacturing
Definition & Timeline

2000-2010:
- Build platforms are getting bigger, resolution is getting better, building time is reduced and prices for machines start to get lower
- New materials are available: Nanocomposites, high-elongation materials, high temperature resistant materials, improved mechanical properties and bio-compatible materials
- Formation of ASTM committee for producing standards on testing, processes, materials, design and terminology in AM
- EnvisionTec introduces first stereolithography machine using direct light processing (DLP) technique

2010-now:
- AM is adopted by many industries as a valid production method
- Capabilities of machines are extended even further (materials, resolution, build sizes)
- AM is reaching the private sector with affordable FDM, SLA and DLP printers
The project consortium

- European project und H2020 programme
- 12 partners from 5 countries
- Project duration: 2015/10-2018/09
- Budget: 5M €
- Call: H2020-NMP-PILOT-2015
- Project number: 685937
Additive Manufacturing

Polyjet technology

Few numbers....
100’s of jets per head
30-80 nanograms drops
± 10 microns drop accuracy
± 5% drop to drop uniformity
Up to 40 KHz jetting frequency

Image Courtesy of Stratasys Ltd

Source: Stratasys
Additive Manufacturing

Polyjet technology

Voxel (volumetric pixel):
- a volume element representing a value on a regular grid in three dimensional space.

This is analogous to a pixel, which represents 2D image data in a bitmap.

Image Courtesy of Stratasys Ltd

Source: Stratasys

Black rubbery material (Tango +)
White rigid material (Vero white)
Grey scale
Shore hardness scale
Additive Manufacturing

Material development

- Ceramic enhanced material
- Electrically conductive material
- Lightweight polymer material
- High strength polymer material
Concept of requirements for ceramic inks
Frame conditions given by the process and the aspired applications:

- Maximum particle defined by printhead’s orifice: $d_{100} < 500 \text{ nm}$
- Too much NANO is not helpful -> Increased viscosity

Compromise:
“Large“ nanoparticle size and small specific surface areas needed

- a) Microsized particles, b) nanosized particles, c) Change of polymer mobility with distance from ceramic nanoparticles, showing a pronounced amount of immobilized polymer in the composite causing a pronounced viscosity increase.
Additive Manufacturing

Conductive ink

Classic:
- Screen Printing and Photolithography

3D Printing:
- No material yet available
  - Polymer with silver nanoparticle
- concurrent properties:
  - Low Viscosity
  - Low resistivity (High metal content)
  - Surface tension
  - Small non agglomerate particles

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids %</td>
<td>≤50% w/w (as starting points)</td>
<td></td>
</tr>
<tr>
<td>Particle size</td>
<td>D(50) = 75-90 nm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d(90) = 95-130 nm</td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>12-20cP at printing temperature (&lt;60°C)</td>
<td>It is not recommended to heat PVN inks above 60°C</td>
</tr>
<tr>
<td>Surface tension</td>
<td>25-35 dyn/cm</td>
<td></td>
</tr>
</tbody>
</table>
| Stability test at room temperature (1 month) (Shelf life test) | Viscosity change ≤5%  
Particle size change ≤5% | Re-dispersible by mild shaking                    |
| Stability test at 60°C (8, 24 hours) (Stability during printing time) | Viscosity change ≤5%  
Particle size change ≤5% |                                                  |
| Accelerated sedimentation rate | <0.38 μm/sec @ T=10% transmission                | Tested with Luminizer centrifuge                  |
| Jetting test                  | Jetting latency > 10 min                         |                                                  |
High strength ink

- High viscosity of polyimide precursors
- Slow kinetics
- High temperature tolerance needed
- Solution polymerization is a challenging process for inkjet formulation

Initial ink requirement (STR) reveal basic limitations of solution polymerization approach

Novel approach to be studied
Additive Manufacturing - Applications

Multi material

- Creation of parts with functionally graded materials:
  - Hardness
  - Flexibility
  - Adhesive properties
  - Stiffness
  - Color

Possible Applications:

- Compliant joints
- Artistic sculptures
- Heat Dissipation
Additive Manufacturing - Applications

Embedded components

- Objects can be embedded due to layer-by-layer build-up
  - Circuits
  - Sensors
  - Monitors
  - Threaded rods
  - Etc.

Possible Applications:
- Toys
- Lighting devices
- Food monitors

Image Courtesy of Berkeley University

Images Courtesy of Disney Research
Additive Manufacturing - Applications

Printed electronics

- Pre-Assembled Parts directly printed
  - Use of sacrificial support material
  - Gaps of few hundreths µm between parts
  - Removal of support leaves captive assembled linkage

- Possible Applications:
  - Physical Working models
  - Locomotive robots
  - Articulated Models
  - Prosthetics

M. Bächer et al. „Fabricating Articulated Characters from Skinned Meshes“, ACM Trans Graph, 31 (4), 2012

S.M. Felton et al. „Robot Self-Assembly by Folding: A Printed Inchworm Robot“, ICRA Conference 2013
Additive Manufacturing – Trends & Challenges

- Materials:
  - Broadening of available materials; solid loaded inks & polymers
  - Digital materials & integration of discrete parts
  - Biomaterials (tissue scaffolds, organs)
- Design:
  - Specific tool representing AM functions & interactions; simple design for complex shapes
- High throughput & build size:
  - Multinozzle array print heads
  - Integration of additional processes (subtractive / finishing)
  - Large scale parts
- Modeling, Sensing and Process Control:
  - Transport phenomena, temperature cycles, process models
  - Access to build chamber for sensors
  - Integration of control algorithms for real-time adjustments of building process

Source: Stratasys, Ltd.
Image Courtesy of Shapeways

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Image Courtesy of Shapeways
Conclusion

- A New Industrial Revolution of connected objects is happening
  - IT Advances:
    - Cloud storage
    - Calculation capacities
  - Operation Technologies advances:
    - Digital system Integration
    - AM processes
    - Materials
- Changes to come:
  - Mass customisation
  - Higher productivity (predictive maintenance, automatization, …)
- It is up to us to make this revolution Human-Centred
  - Improvement of Human-machine interface
  - Telepresence
  - Training
Acknowledgements

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