Future Trends in Additive Manufacturing and Space Applications

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Who Am I?

• Cofounder of Z Corporation
  - Chief of Materials Development
  - Created many of the software algorithms for full-color 3DP
  - Left in 2005 to work at MIT

• CTO of Viridis3D
  - Develop materials and processes for industrial 3D Printing
  - Presently working on a robot-based 3D Printer for ceramics and foundry applications

• MIT: Research and teaching in Materials Science

• James H. Bredt was my father
  - Program Administrator at NASA in the 70’s and 80’s
  - Worked on Manufacturing in Space
  - Worked on Environmental Controls for long-term missions.
  - Source of several of the metaphors I may use in this talk
Outline

• AM Industry Trends
• Innovation in AM
• Review by Technology
• Conclusions
2012-13 Industry Consolidation

~ \( \frac{3}{4} \) of Market Share

Corporate Acquisitions are NOT Good for Technological Innovation!
Low-End Race to the Bottom

Explosion of low-cost AM systems are attracting attention of large players.

Innovation is being directed towards cheaper equipment, not to expanding capabilities.
Tissue Engineering

Low-end systems are getting adapted where possible in R&D efforts
Biomimetics, Soft Robotics, Heterostructures

OptoMEC

Harvard Lewis Grp.

Nanoscribe

Borgatti

Harvard Lewis Grp.

Indiegogo
Industrial 3D Printing

Smaller companies are finding a niche in the industrial market neglected by large players.
Review of Trends by Technology

...and applications in space...

...either on a space station or on Moon base.
• Operation in zero G or with Moon gravity
• Large-scale production must be in the vacuum
• Raw material sources might include metallic asteroids, materials refined from Moon dust
• Biopolymer from algae farm or food processing
How Do You Invent a 3D Printer?

- Select class of materials, accuracy and build size
- Select or invent dispenser
- Refine material selection to achieve best performance
- Manipulator follows from size, accuracy, and environmental requirements
Fused Deposition Modeling

- Most people who have heard of ‘3D Printing’ think this is it.
- Build material is thermoplastic supplied as a filament
- Extrusion head travels over platen dispensing a bead
- Requires supports, may be different material from build
Process Features

- ABS, PLA, polyamide, acrylic, wax.
- Ceramic and metal powders as fillers
- Build rate: ~0.5 in/hr
- Build size: up to 36x24x36”
- One of the few methods that gives plastic parts at nearly full density
- Has already been flown in space
- Some materials might work in vacuum
- Materials such as PLA and cellulosics could be available from food proc.

Companies: Stratasys, HP, Beijing Yinhua

JECS 21, 1485-1490 (2001)
Low-end FDM

- Presently driving the AM industry.
- Systems costing less than $5000
- Kits as low as $75
- Size typically 4-6 in.
- Same materials as high-end FDM
- Companies: Stratasys (acq. of MakerBot) 3Doodler, Fabbster, 3D Systems (BitsFromBytes) RepRap, Fab@Home, Delta Micro Factory, and dozens of others
Stereolithography

- Build material is liquid photopolymer in tank
- Laser spot travels over top surface, curing polymer in layers.
- Ceramic and metal fillers are being explored
- Requires gravity, atmosphere. Petrochemical & have strong odor.

Companies: 3D Systems, FormLabs CMET, TNO
Laser Sintering/Melting

- Build material is powder in a leveled bed.
- Laser spot melts (or sinters) powder grains in layers
- Bed is lowered in steps, and powder is spread by roller.
- Layers are supported during build by unbound powder
Process Features

- Fully dense stainless steels, tool steels, nickel alloys, Co-Cr, Ti, Cu, Al
- Best mechanical strength
- Polymers: ABS, Polyamide, PEEK
- Build rate ~ 5 mm$^3$/sec
- Build size: 10x10x12” (metals)
- Up to 22x22x30” (plastics)
- Requires gravity
- Metals probably work BETTER in vacuum

Companies: 3D Systems, EOS, Concept Laser, Realizer, Phenix, MTT, Arcam (E-beam)
Laser Cladding

Metal powders applied in stream to laser spot on substrate
System is **robotic**, no powder bed. Parts up to 3 meters.
Zero G, vacuum operation might be feasible

**Companies:** Optomec, POM
Ballistic Particle Manufacturing

Droplets of molten polymer are shot from a DOD printhead onto a substrate using a 6-axis robot.
No size limitation, but build rate is very slow.
Possible applications with metals, should work in zero G, vacuum.

Companies: None – BPM Inc. failed in 1997
Inkjet on Platen

- Material is photopolymer liquid dispensed through an inkjet printhead. Cured with UV lamp
- Acrylics, epoxies, elastomers.
- Features ~.001 in.
- Build size: up to 20x15x8”
- Build rate ~1 in/hr
- Can build functionally gradient parts, such as elastomers with varying stiffness.
- Can work in zero G
- Requires atmosphere, ventilation.

Company: Objet (merged 2013 with Stratasys)
Inkjet on powder

- Powdered substrate bonded by solvent printed through inkjet printhead.
- Filled polymers, resin-bonded sand, metals (EX One)
- Ceramics, refractories, cements (Viridis)
- Build rate: ~2 in/hr (ZCorp)
- Size: Up to 80x120x40“ (VoxelJet)
- Robotic system available soon (Viridis)
- Powder-based system requires no support structures
- Requires gravity, atmosphere.

Companies: 3D Systems (acq. ZCorp 2012), EXOne, VoxelJet, Viridis3D
Laminated Object Manufacturing

- Adhesive-coated paper is laminated onto a growing stack.
- A laser or cutting tool carves the contours of each layer.
- Unused material is diced into cubes and removed after.
- Very fast & reliable machine, materials not too specialized
- Full color is available, first since ZCorp in 2001.
- Can work in zero G, doesn’t require atmosphere.

Companies: MCOR, Helisys (closed)
Digital Light Processing

- Photopolymer bath cured by projected light
- Layers cured against window at bottom of tank.
- Platform is stepped upwards.
- Simple, reliable architecture
- Build rate ~1 in/hr.
- Resolution determined by pixel size of projector
- Fine features for jewelry pattern making
- Ceramic-filled resins are possible
- Might be feasible in zero G
- Requires ventilation

Company: EnvisionTEC
Conclusion

• Several technologies are feasible for making plastic replacement parts in space
• Robotic systems best for building large structures
• Metal powder or wire-feed machines building of large structures (e.g. rockets) could work very well in vacuum
• To detach raw material supply from Earth, need metals source:
  Asteroid or electro-refining of Moon rock