Asian Journal of Medicine and Health Sciences Vol 2 Issue 2 November 2019

BRIEF REPORT

ADDITIVE MANUFACTURING IN MEDICINE.

Pandurangan T

Faculty of Medicine, University Kuala Lumpur Royal College of Medicine Perak, Ipoh

Corresponding Author
Prof. Pandurangan T
UniKL RCMP, No. 3, Jalan Greentown, 30450 Ipoh, Malaysia.
Email: thunga@unikl.edu.my

Introduction

In Additive Manufacturing 3-D model data is used to make objects, by layer upon layer, using a machine. This is opposite of subtractive manufacturing methodology. It is also known as “rapid prototyping” and “3D printing”. This is akin to printing on a paper the same material over and over again several times till that printed matter builds up into a 3-D image. Actually in 3-D printing process a whole object is converted into thousands of tiny little slices by a computer and then it is built from the bottom-up, slice by slice.

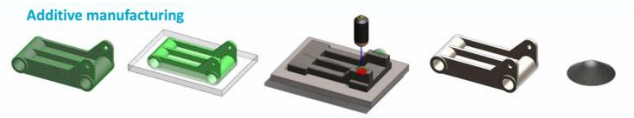
History of Additive Manufacturing[1, 2]

The first Stereo lithography was first invented by Charles Hull in 1984. The first commercial 3D printing system was launched by 3D Systems in 1987.

Starting from the 21st century different human body parts have been fabricated by different institutions worldwide, viz. miniature kidney, blood vessel, skin and heart. Non-living objects like prosthetic leg and artificial joint parts have also been manufactured.

Additive Vs Subtractive manufacturing

In subtractive manufacturing, the part is machined out from a block of raw material. The excess material is removed, until the desired shape is formed. The subtractive process creates waste material. The complexity of the part is limited.



In additive manufacturing, the part is created by depositing the material in the desired locations in a layer-by-layer manner. Able to create complex geometries. Minimized wastage of materials.

Categories of AM systems

There are 7 categories of AM systems:

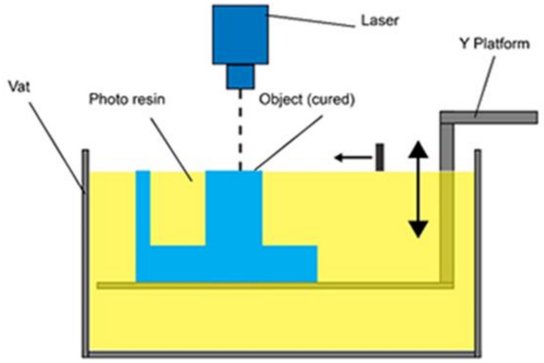
- Vat Polymerization
- Powder Bed Fusion
- Material Extrusion
- Material jetting
- Binder Jetting
- Sheet Lamination
- Direct Energy Deposition

Vat polymerization[3, 4]

Method:
UV source scans and traces out the cross-section of the object on the liquid resin.
The resin cures and solidifies on UV exposure.
The build platform moves down by one-layer thickness.
Re-coater spreads an even layer of resin over the object.
The tracing and curing process is repeated.

Powder-Bed Fusion[5, 6]

Principle: Energy source such as a CO2 laser or electron beam is used to fuse powder particles together.
Building Material used:
Polymer
Ceramic
Metal powders



Powder-Bed Fusion[5, 6]

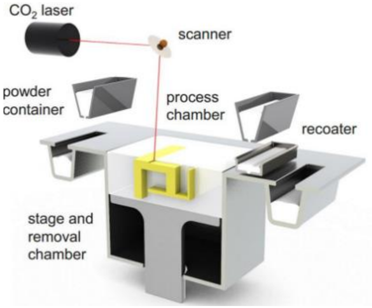
Principle: Energy source such as a CO2 laser or electron beam is used to fuse powder particles together.

Building Material used:

Polymer

Ceramic

Metal powders



Method:

Laser beam scans and traces out the cross-section of the object on the pre-heated powder bed. Energy of the laser bonds (sinters) or melts the powder particles causing them to fuse together.

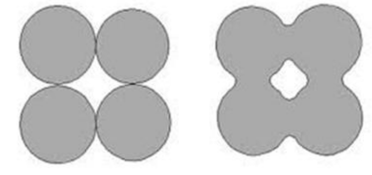
The build platform moves down by one-layer thickness.

A thin layer of powder gets spread over and the process repeats.

Happens in an inert environment such as nitrogen.

Fusing occurs below melting temperature.

Printed parts are porous in nature due to gaps in-between particles.



Representation of the initially unsintered powder particles. Represention of Sintered Powder Particles

Applications

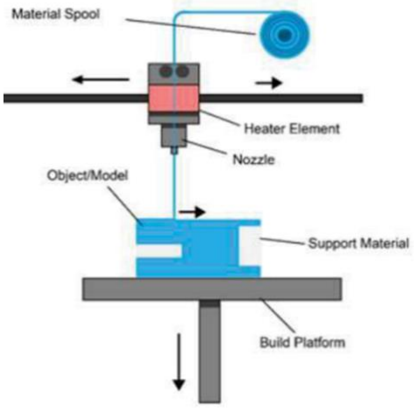
Used in the medical field such as orthopaedic implants & scaffolds

Functional prototypes

Material Extrusion[7, 8]

Principle:

In this the required material is expressed from a nozzle and is subjected to heat. This will make the material pliable and it is deposited layer upon layer on a platform. As each layer is deposited the machine moves in a horizontal direction, whereas the platform moves in a vertical direction.



Method:

First layer is built as nozzle deposits material where required.

The following layers are added on top of previous layers.

Layers are fused together upon deposition as the material is in a melted state.

Materials:

The Material Extrusion process uses polymers and plastics.
E.g.: ABS (Acrylonitrile butadiene styrene), Nylon, PEI (Polyetherimide), and PEEK (Polyether ether ketone)
PEEK is finding increased use in spinal fusion devices and reinforcing rods. It is also used with a high-resolution MRI for creating a partial skull replacement in neurosurgical applications.

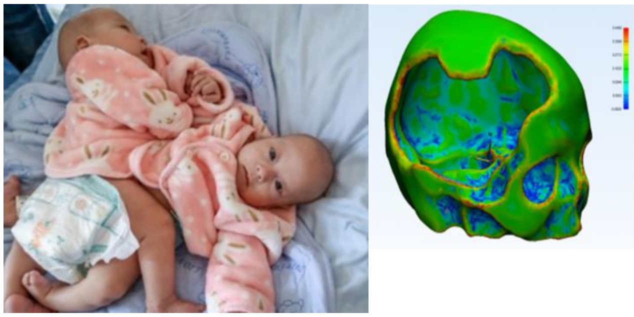
Material Jetting[9]
Principle:
In this method droplets of material used is sent as a jet form using heat or piezo-electric energy, on a platform. This is then solidified using UV light. The first layer thus built is followed by several other layers deposited over and over again in a horizontal manner on the platform.
Method:
The print head is positioned above build platform. Droplets of material are deposited from the print head onto surface where required, using either thermal or piezoelectric method. Droplets of material solidify and make up the first layer. Further layers are built up as before on top of the previous. Post processing includes removal of support material.

Medical Applications of Additive Manufacturing[10, 11, 12, 13]

- Planning and simulation of complex surgery
- Customized Implants and Prosthesis
- Tissue & Organ Engineering

Planning and simulation of Complex surgery
The process involves converting CT, MRI or Ultrasound scan data into a 3D model
The 3D model is then printed into a physical model which can be studied
AM enables surgeons to practice surgery on a precise model and master the essential details before the actual operation
Hands on experience help improve success rates of surgery
Surgeons able to visually inspect the exact location and/or profile of the defect, which might not be clear on traditional scanning methods.

Case Study 1:
Surgeons at the Fudan University in Shanghai used CT and MRI data to reconstruct a 3D model of conjoined twins who were born fused at the abdomen & pelvis.
The surgeons determined that they would start with separating the liver and the pelvic bone, followed by a new team of surgeons to work on the babies' intestines and bladder.
The surgery lasted 12 hours. The twins were successfully separated
Fudan University has used 3D printing in the separation of 9 pairs of conjoined twins.



Case study 2:
Two teenagers in Kochi India, suffered from congenital heart disease. Due to the teens' unique

structural defects a surgery posed a risk on the lives of the patients.

A paediatric cardiologist and a radiologist gave full heart evaluations and built physical 3D printed models using the scanned data. Surgical procedures were planned based on the models and surgery was carried out successfully.

Case study 3:

A patient had extensive defect in the skull due to a traumatic injury.

A CT scan of the patient's head was taken and a digital 3D model built from it. The shape and size of the required implant was digitally created using this scanned 3D model which allowed for a good fit.

The mould was 3D printed and used to cast the final implant out of a biocompatible polymer, which was then successfully implanted in the patient.

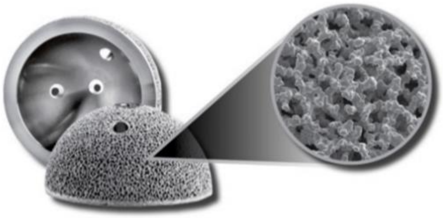
Case study 4:

A 15 year old girl was suffering from severe skeletal deformity of the left hip. Skane University Hospital in Lund, Sweden teamed up with Materialise to design a custom acetabular implant.

CT scans were used to reconstruct a digital 3D model which was used as a template to design the implant.

The designed implant was 3D printed in titanium.

A porous surface was designed to maximize bone regrowth.



Implants and prosthesis:

Traditional implants and prosthesis were based on available anthropometric data and standard sizing.

Standard sizing doesn't provide a good fit to many patients due to the uniqueness of the defects.

Creating customized implants were expensive and time consuming.

With AM, customized implants and prosthesis were able to be manufactured and at a much lower cost and time.

Scan data is used to create a digital 3D model which can be printed in 3D.

No extra cost of customization and complexity.

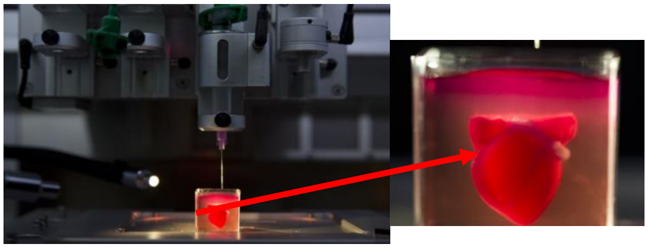
Better bio-compatibility.

3D printed heart[14]:

On 15th April, 2019, Israeli scientists demonstrated a 3D printed heart from human cells.

The heart was the size of a rabbit's heart.

They further stated that may be in 10 years organ printing may become a reality across the world.



3-D printed skin:

In May, 2019, IIT Delhi bio-printed human skin. This has great potential in treating burns & other major wounds.

3-D printed lung:

In May, 2019, scientists in George R. Brown School of Engineering bio-printed lung with blood vessels. This has opened a tremendous pathway for organ bio-printing and can reduce the need for organ donors.

Limitations for Bioprinting

Vascularisation of organs:

The limitation for AM, viz. vasculature of printed organs, can be overcome by including pre-fabricated printed vessels into the 3D printed organ.

This permits faster integration of the transplant into the host circulatory system.

Cell sources:

Adult stem cells or induced pluripotent stem cells may be required. Has its own health risks.

Conclusion

Additive manufacturing has tremendous potential in the future in the field of medicine, especially in organ transplants.

References

1. Prince JD. 3D printing: an industrial revolution. Journal of electronic resources in medical libraries. 2014 Jan 1;11(1):39-45.
2. Goldberg D. History of 3D Printing: It's Older Than You Are (That Is, If You're Under 30). Autodesk, [Online]. Available: https://redshift. autodesk. com/history-of-3d-printing/.[Accessed 30 10 2019]. 2014.
3. Adam GA, Zimmer D. Design for Additive Manufacturing—Element transitions and aggregated structures. CIRP Journal of Manufacturing Science and Technology. 2014 Jan 1;7(1):20-8.
4. Thompson MK, Moroni G, Vaneker T, Fadel G, Campbell RI, Gibson I, Bernard A, Schulz J, Graf P, Ahuja B, Martina F. Design for Additive Manufacturing: Trends, opportunities, considerations, and constraints. CIRP annals. 2016 Jan 1;65(2):737-60.
5. Gusarov AV, Laoui T, Froyen L, Titov VI, Tolochko NK. Numerical simulation of laser solid state sintering of loose titanium powder. InProc. EURO RP 2001, 10th European Conference on Rapid Prototyping and Manufacturing 2001 (pp. 1-5).
6. Kruth JP, Peeters P, Smolderen T, Bonse J, Laoui T, Froyen L. Comparison between CO2 and Nd:YAG lasers for use with Selective Laser Sintering of steel-copper powders, Revue International de CFAO et d'informatique graphique, 1999;13(4):95-112.
7. Evans MA, Ian Campbell R. A comparative evaluation of industrial design models produced using rapid prototyping and workshop-based fabrication techniques. Rapid Prototyping Journal. 2003 Dec 1;9(5):344-51.
8. Sambu S, Chen Y, Rosen DW. Geometric tailoring: a design for manufacturing method for rapid prototyping and rapid tooling. InASME 2002 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference 2002 Jan 1 (pp. 149-161). American Society of Mechanical Engineers.
9. Sachs E, Cima M, Cornie J. Three-dimensional printing: rapid tooling and prototypes directly from a CAD model. CIRP annals. 1990 Jan 1;39(1):201-4.
10. Bibb R, Eggbeer D, Evans P, Bocca A, Sugar A. Rapid manufacture of custom-fitting surgical guides. Rapid Prototyping Journal. 2009 Sep 25;15(5):346-54.
11. Kontio R, Björkstrand R, Salmi M, Paloheimo M, Paloheimo KS, Tuomi J, Mäkitie A. Designing and additive manufacturing a prototype for a novel instrument for mandible fracture reduction. Surgery S. 2012 Jan;1:2161-1076.
12. Poukens J, Laeven P, Beerens M, Nijenhuis G, Sloten JV, Stoelinga P, Kessler P. A classification of cranial implants based on the degree of difficulty in computer design and manufacture. The International Journal of Medical Robotics and Computer Assisted Surgery. 2008 Mar;4(1):46-50.
13. Salmi M, Tuomi J, Paloheimo KS, Björkstrand R, Paloheimo M, Salo J, Kontio R, Mesimäki K, Mäkitie AA. Patient-specific reconstruction with 3D modeling and DMLS additive manufacturing. Rapid Prototyping Journal. 2012 Apr 20;18(3):209-14.
14. College of Engineering, Carnegie Mellon University. "3D printing the human heart." Science Daily. Science Daily, 1 August 2019.