The state of 3D printing technologies: A review

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Abstract. This review paper is written to present the 3D printing technologies from all aspects which are commercially available. Since 3D printing is evolved rapidly over the past decade, there are a number of considerable applications that are well-known in almost all areas and disciplines. This paper will focus on the existing 3D printers, its advantages, and disadvantages and applications. Furthermore, this will provide a sufficient general review in the development of 3D printing technologies.

Introduction

A developed technology in the late twentieth century is termed as additive manufacturing (AM) and known as implementation of three-dimensional (3D) fabrication is growing widely in almost all areas and starting to be a key process in considerable manufactural areas. In other words, this innovation which known as the process of building layer-by-layer using solid CAD model, is a major role in the fourth industrial revolution (IR4.0) and advancing engineering future, consequently our globe. In addition, in single session it is able to conclude fabrication cycle of whole part [1]. Moreover, this advancement cannot only leave impacts on efficiency of industry, energy, economic, and etc, but it can also positively contribute in the environment, sustainability, and our interaction with our world.

The base idea of printing can be described as ink is deposited in the page in one layer, while in additive manufacturing material is deposited in manner which the layer over another. This advanced technology makes creating simple or even complex shape 3D objects with total flexibility and minimum amount of material wastage and cost. Additionally, all these are compelling reasons for replacing subtractive manufacturing with additive manufacturing.

This review will critically be evaluating 3D printing technologies in general bases going through types and scales. Moreover, by highlighting evolvement, advantages, disadvantages of each three-dimensional printer.

Discussion

This technology considered to a major key technological revolution, as it plays a huge economical role [2]. All this due to the fast-developing prototype creating and producing customizable parts, as these points considered to be the main reason for the growth and demand in almost all sectors. Further, in three-dimensional printing there are seven 3D printing techniques, and they are applicable with a huge number of materials in broad classifications such metals, ceramics, polymers, composites and hybrids in areas such automobile, aerospace, health-care and medical, construction, electronics, food and etc.

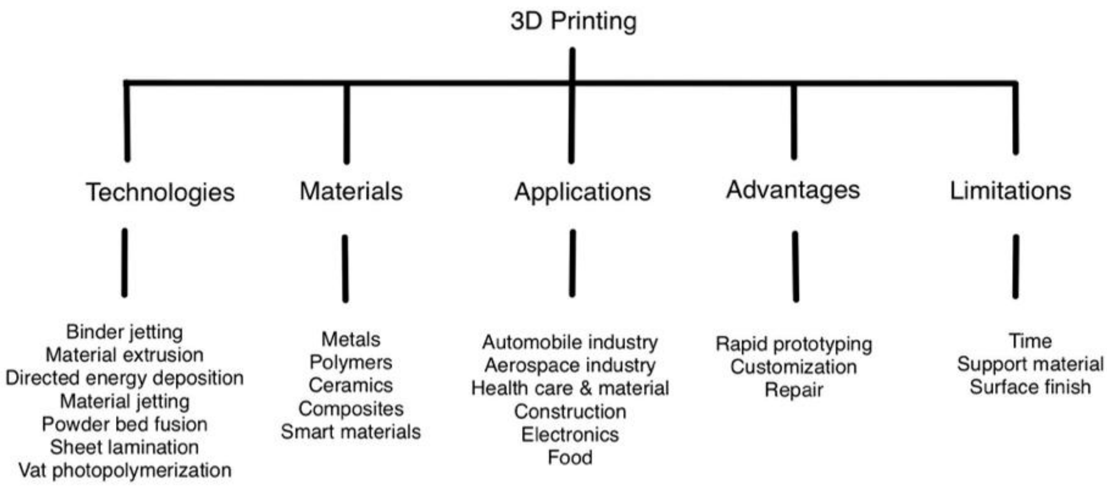

Fig. 1. *Flow chart of additive manufacturing*

One of the advantages of additive manufacturing can be summarized in rapid prototyping, due to the ability to evaluate 2D drawing of a design by fabricating 3D printed prototype using a wide range of material. Also, 3D printing is heavily used for repairing purposes. However, there some limitation in additive manufacturing such consuming size and time, as most printers fabricate small build volume of about 400x400x400 mm3 only binding jetting and directed energy deposition have a larger build volume than the rest, of about 2000x2000x2000mm3 [3].

Vat-Polymerization

Vat-polymerization method is the process that build an object by hardening a bulk liquid, as 3D photopolymerization explained as the using monomers or oligomers sated as liquid. Additionally, in the process the liquid is photopolymerized when exposed to light (UV) with a specific wavelength. Yet, this method of photopolymerization usually shrinks the material [2].

Vat-polymerization method is highly used in medical and dental devices [4]. For example, this method of additive manufacturing is being used in single layered or dual layered acrylic resin materials, however dual layered devices provide more comfort to patient, improved fit, and can be adjusted for fit compared to single layered devices. In addition, these devices can be occlusal made biocompatible photosensitive acrylic esters resins to be photopolymerized by this method [4]. Vat-polymerization technologies is divided into different categories as they differ in the light source used by the printer: stereolithography (SLA), direct light processing (DLP), and liquid crystal display based (LCD), also called daylight polymer printing (DPP).

Stereolithography (SLA)

Stereolithography (SLA) 3D printing technology processes photo-curable resins by a focused light beam with a wavelength range 300 nm-700 nm. In addition, this light is produced by the Digital Light Processing (DLP) projector and goes through the lens imposed on a layer of resin. Yet, the photo-polymerization reaction occurs and the resins transform from the liquid state to the solid state. To perform the motion needed of the Z-stage platform, an Arduino microcontroller controlling a stepper motor and ball screw is used with software to control other slicing parameters. SLA additive manufacturing technique and additionally used for rapid prototyping (RP), it uses the one at a time layering technique of 2D slices in order to create the 3D object, all this based on photo-polymerization reaction of resin [5]. The printing of an object starts from the top and going downward vertically. SLA 3DP offers the best resolution compared to any other 3DP techniques [6].

Surface roughness known to be major issue for most 3D printing techniques, because of adding discretized printed layers. Projection micro- Stereolithography (PµSLA), is one of the AM processes that known to be capable to 3D print required objects with high level of accuracy by capturing minor features of the objects compared to other methods. However, surface roughness is variable when process parameters change.

The LED transmitting a 405 nm beam through a spreading optic in order to be able to cover the micromirror array device (DMD) entire surface. On the PNG, there is a black pixel required to turn the corresponding micromirror. This micromirror is turned to a position reflect the light to the heat sink, while a white pixel is used to reflects the light on the photosensitive resin in the vat for the specified exposure time. As a result, this transmission of light photopolymerize the photosensitive resin, and the resin is squeezed to print layers. Keep in mind before starting UV exposure, the distance of squeezing between transparent PDMS window and cured layer, should be on the corresponding required thickness. The facilitating is for the polymerized layers from PDMS window. After that, the vertical translation platform goes upward by a the corresponding distance of the thickness [7, 8].

Digital Light Processing (DLP)

If compared stereolithography printing and digital light processing printing we will find that DLP has a faster print times, due to that each layer revealing at once compared to tracing intersectional field by a laser. The projection of light on the photosensitive resin is with a digital micromirror device (DMD) on the LED screen or UV light, where DMD can be explained as the Miro speakers controlling light projection on the structure surface generating light pattern [9].

Liquid Crystal Display (LCD)

LCD display as system of imaging. To explain this 3DP technique, a light is lighting onto photosensitive resin through flat LCD panel. Moreover, this technique of fabrication force light not to expand, which result in less distorted pixels and eliminates this issue, as this issue occurs in DLP 3DP. Comparing LCD with SLA, LCD does not require scanning point-by-point as you are able to process a full layer at once, which result in faster printing. LCD printers known to use UV or LED arrays as the light source in the LCD flat panel [10].

Continuous Liquid Interface Production (CLIP)

Continuous liquid interface production (CLIP) is an additive manufacturing process different than SLA as it processes a preamble widow of oxygen to the inhabitation of photopolymerization at its surface preventing adhering. In CLIP, resin able to flow to “dead zone” liquid at the surface of window leading to a layer-by-layer printing of an object.

Fused Deposition Modeling (FDM)

Material extrusion (MEX) printing, also called fused deposition modelling (FDM) or fused filament fabrication (FFF), is a popular AM process [11]. MEX is known to hold the advantage of low material and energy requirements of thermoplastics. As a result, MEX technology by far is the most economical AM technique that provides customizing across many fields; against all others [12]. FDM as the name implies, is 3D fabricating technique uses fused material to be deposited in a layer-by-layer manner in order to 3D print parts.

Materials used for FFF technology are thermoplastics polymers, Poly lactic acid (PLA), Polycarbonate (PC), and Acrylonitrile Butadiene Styrene (ABS) [13].

Material Jetting (MJ)
Material jetting (MJ) 3DP technology uses a process similar to traditional inkjet printer, as the prating head prints various photopolymer droplets to be cured by a UV lamp. In addition, this is a layer-by-layer printing process that result in a 3D printed object [9].

Drop-on-Demand Droplet Jetting (DOD)
Drop-on-demand droplet jetting is a new method in the additive manufacturing world. This new technology holds a research progress for metal, colloid, and liquid resin materials. However, since this is a new fabrication technique in 3DP, there is a limitation in researches and sources in some specific areas. With the highly increase in demand of quality, droplet jetting 3DP technique is based on the FDM process. Droplet jetting technology produces and stacks precisely the formed micro droplets.

Poly-Jet
Poly-jet 3D printing (PJ-3DP) is a method used in 3D printing that uses droplets of jetted photopolymers to be cured by a UV light source, in order to 3D print layer-by-layer a product. In PJ-3DP via inkjet, selective photopolymers resin layers are jetted in order to fabricate a build-tray. With the composition of multiple micro-jetting heads, the head of printing prints a 16 μm thick resin layer to the build-tray, bearing the cross-sectional profile of bult [14].

Nano-Particles Jetting (NPJ) by XJet
Nano-particles jetting (NPJ) solution-based deposition is a technology created by XJet under the category MJ, and the process known to additively manufacture by small solid-state substance to be hold/contained in a carrier solution liquid. Advantages of nano-particles jetting (NPJ) by XJet, able to print dense, detailed featured objects with a thickness of layer of 10 μm with 20 μm jetting resolution. However, two major limitations, which are the inability control the deposition pattern in a precise manner, and nozzle clogging formed by precipitates [15].

D. Binder Jetting (BJ)
Binder jetting (BJ) is an additive manufacturing process that joins powder feedstock by organic binder. BJ method of 3DP prints layer-by-layer in order to fabricate the desired complex shape [16]. Keep in mind, this fast-printing technique is applicable for ceramics, metals, or etc [17].

The BJ 3DP process uses selectively deposited liquid binder to selected raw material powder bed. In addition, this powder material is produced by an inkjet print head that prints layer-by-layer [5].

Powder-Based Fusion (PBF)
Powder-based fusion (PBF) technology known to be widely spread worldwide over last couple of years in industrial applications, and specially in medical sector. To explain PBF generally, the process of starts by melting fed wire in inert or vacuum by laser or electron beam, while product moves in three-dimensions. As a result, to build layer in x-y plans, scan by powder feed and melting system selectively build a layer. After that, the built layer moves down in z axis in order be able to build the next layer. All this three-dimensional printing process is controlled by computer aided design (CAD) program to fabricate desired 3D object.

In PBF technology, there four categories of Powder-based fusion additive manufacturing technology, and each one differs in printing process. These categories are selective laser sintering (SLS), selective laser melting (SLM), electron beam melting (EBM), and multi jet fusion (MJF) [19].

Sheet Lamination (SL)
Helisys company innovated sheet lamination technology in 1991, where the process uses a laser to cut fused sheets together while it is guided by a digital system to fabricate the parts [20].

Moreover, there are many types under the category of sheet lamination which varies with its materials and processes, as there are LOM for papers, CAM-LEM for alumina and other ceramics, SDL for standard type paper, UAM for a variety of material combinations. Another is composite based additive manufacturing (CBAM) process which is a first-generation assembly methodology innovated by Ropert Swartz. Technique begins by a load of fiber sheets, carbon, glass, or Kevlar to be put in machine, then mats considered layers of the object is moved to printing stage [21]. Also, selective lamination composte object manufacturing (SLCOM) process, which is an additive manufacturing process that fabricates fibre reinforced polymer (FRP) composites. This technology selectively cut and bond woven composite sheets [22].

Direct Energy Deposition (DED) / Laser Cladding

Direct energy deposition (DED) (also called laser cladding) is a metal additive manufacturing (MAM) process that uses high power laser as well as coaxal powder delivery system to 3D print 3D metal objects layer-by-layer. This promising technology able to fabricate large metal products with complex shapes [19]. DED technology is considerably very fast freeform manufacturing process. Laser cladding is efficient to manufacture near net shapes for engineering applications and medical applications [23]. Laser cladding known to offer many advantages for modern application, as when parameters are properly set the quality reach a very good level. However, DED 3D printed objects have high porosity and poor mechanical properties [24, 25]. DED categories are laser engineered net shaping (LENS), aerosol jet technology, electron beam additive manufacturing (EBAM), laser deposition welding (LDW), and wire and Arc additive manufacturing (WAAM).

Conclusion

3D printing is the manufacturing technique of the present and the future. A broad spectrum of materials can be processed for pro- ducing a component and new material are being developed regu- larly. This technique has found application in industries like automobile, aerospace, health and medicine, electronics, construc- tion, food and many more for the purposes like rapid prototyping, modifications and repair. The range of opportunities in 3D Printing is extraordinary, specifically in aerospace and medicine. With regards to future perspective, high strength lightweight materials for their application in the aerospace industry could be very bene-ficial. Similarly, the growth and development of biomaterial for producing artificial organs for humans would be favorable as the number of organ donors is very less as compared to the number of recipients. A personalized, biocompatible and implantable 3D artificial liver can be printed using the patient's hepatic cells, who are suffering from the severe hepatic disorder which increase the therapeutic efficiency of liver transplantation. Moreover, 3D Printing can also be used for facial reconstruction and bone regen- eration and repair. The most useful area for research in 3D printing is reducing the time it takes for printing a component as it being one of the major drawbacks of this technique. In the present sce- nario considering the advantages and limitations this technique cannot be used as a standalone process but it should be incorpo- rated in the multistage process of manufacturing of a product. Furthermore, according to ASTM Standard F2792, 3D printing can be classi- fied into seven major categories including binder jetting, material extrusion, directed energy deposition, material jetting, powder bed fusion, sheet lamination and vat photo-polymerization.

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