

Types and applications of 3D printing

Yichen Xu *

Department of Wickham International School, Hangzhou, China

* Corresponding Author Email: yaoqun@gttis.com.cn

Abstract. 3D printing technology is a rapidly advancing field. Currently, it is widely employed globally across diverse sectors. This technology is increasingly utilized in large-scale customization, healthcare, automotive, locomotive, and aerospace industries, encompassing all types of open-source designs. 3D printing technology enables the direct creation of objects through the layer-by-layer deposition of materials based on computer-aided design (CAD) models. Looking ahead, 3D printing is poised to integrate with numerous emerging technologies, including nanomaterials, presenting promising prospects for further development. Consequently, this paper outlines the fundamental principles of 3D printing technology, its advantages and challenges, recent technological advancements, as well as its future trends and research directions.

Keywords: Additive manufacturing, types, development, application.

1. Introduction

Digital manufacturing technology, also known as additive manufacturing or 3D printing, emerged in the 1980s [1]. Originating from rapid prototyping technology, it creates physical objects from geometric representations by continuously adding different materials. It is a new manufacturing technology that has developed rapidly in recent years.

Although traditional manufacturing triggered the industrial revolution and shaped the world today, it also has limitations and requires new approaches. However, this technology is not enough to reflect the current state of modern manufacturing technology [2]. Mechanical maintenance, moulding, and repair is a complex process involving tools, equipment, and machinery. Traditional manufacturing is a manufacturing method that subtracts from raw materials. As a result, the quality of the final product is constrained by the tooling capabilities employed during the manufacturing process [3]. In contrast, additive manufacturing is a new modern technology that builds objects up layer by layer, adding a cross-sectional layer of material at a time. Therefore, 3D printing technology saves materials and labour, while creating more possibilities. Furthermore, 3D printing technology enhances production speed while simultaneously reducing costs. When manufacturing sites are situated close to their final destinations, fleet tracking technology can facilitate deliveries, leading to savings in both energy and time costs [2].

In the last two decades, 3D printing technology has progressed rapidly, with an ever-growing diversity in materials and forming mechanisms, resulting in parts of increasingly higher quality and precision. This expansion has significantly broadened the scope of applications for 3D printing technology. Initially, additive manufacturing was known as 'rapid prototyping', primarily utilized for swiftly crafting conceptual models of new products to facilitate comprehensive evaluations. As material properties and process repeatability have improved, the role of additive manufacturing has evolved from merely creating prototypes to manufacturing parts for functional testing, tools for injection moulding and sand casting, and ultimately, directly producing end-use components.[3] Currently, additive manufacturing technology is increasingly incorporated into modern mechanical engineering applications, notably in industries such as automotive, locomotive, and aerospace, where it enables large-scale customization. Its ability to reduce waste and the use of hazardous chemicals (like etching and cleaning solutions), coupled with its capacity to utilize recycled materials, sets it apart. Consequently, the recent advancements in synthesizing end-use products from a diverse range of materials (including metals, plastics, ceramics, etc.) and their inherent eco-friendliness have transformed additive manufacturing into a revolutionary technology for innovative manufacturing.

In summary, additive manufacturing technology has emerged as a flexible and potent tool in advanced manufacturing over the past few years. Hence, this paper comprehensively outlines the principles, advantages, challenges, and technical advancements, as well as the future trends and research directions of additive manufacturing.

2. Types of 3D printing

2.1. Materials extrusion

The 3D printing technology enables the printing of various materials such as plastics, food, or even living cells, as well as multicolour printing. One major reason for its widespread adoption is its low cost and the diverse and comprehensive range of products it can produce.

Fused Deposition Modeling (FDM) serves as the pioneering example of a material extrusion system. It utilizes a continuous feed of thermoplastic material, which is heated and extruded through a moving, heated extrusion print head, layer by layer, to construct parts. The advantages lie in its capability to print products in various colours, simplicity, and high speed. Moreover, it supports a wide range of materials. However, its mechanical properties are relatively poor, with limited resolution and a suboptimal surface finish on the printed products [4].

2.2. Materials jetting

Material jetting is also a process in additive manufacturing, involving the selective deposition of building materials. During the ejection of the material, the print head ejects droplets of the photosensitive material, which are then solidified and used to construct parts layer by layer under ultraviolet (UV) light. The advantage of Material Jetting is that it can produce parts with smooth surfaces and high dimensional accuracy, such as ceramics, composite materials, and some biological materials.

2.3. Powder bed fusion

The powder fusion process encompasses electron beam melting (EBM), selective laser sintering (SLS), and selective heat sintering (SHS). EBM primarily utilizes a melting process that employs metal powder and an electron beam [5]. The material is laid on the building platform and heated by the electron beam. SLS employs a high-power laser to sinter specific points on the powder bed. Its advantages lie in the ability to produce large-sized parts with diverse materials, as well as the rapid customization and production of parts with high strength and stiffness [4]. In SHS, the material is dispensed from a powder deposition tank, heated to a temperature slightly below its melting point, laid into a thin layer on a movable building platform, and then processed using a drum. These technologies are frequently employed in fields such as biomedicine, electronics, aerospace, and lightweight structures.

2.4. Sheet lamination

Sheet lamination involves bonding multiple layers of material together to form a component of an object, exemplified by processes such as laminated object manufacturing (LOM) and ultrasonic additive manufacturing (UAM). Its advantages lie in its capability for full-colour printing, low cost, simplified material handling, and the recyclability of excess materials. However, sheet lamination technology also presents certain drawbacks, including limited material diversity and relatively low precision [4].

2.5. Binder jetting

The application of binder jetting lies in producing casting models, raw sintered products, or similar large-volume items from sand. Binder jetting technology can print a diverse range of materials, including metals, sand, polymers, composites, and ceramics. [5] Some materials, such as sand, do not

necessitate additional processing. The key advantage of binder jetting is its capability to print exceptionally large products with a relatively straightforward process and at a lower cost [4].

2.6. Vat Photopolymerization

This process is a key technology in 3D printing, frequently employed, and typically involves the use of lasers, light, or UV radiation to cure photo reactive polymers. [2] Notable examples of this 3D printing technology include Stereo Lithography Appearance (SLA) and Digital Light Processing (DLP). In SLA, a UV laser is directed to the top surface of the resin, precisely curing it at the point where the laser hits. On the other hand, DLP utilizes a digital projector screen to simultaneously project a single image of each layer across the entire platform. [4] The primary advantages of this process lie in its high precision, resulting in smoothly finished printed products, along with a broad material diversity, enabling the creation of numerous high-quality products. Consequently, VAT photo polymerization technology is widely adopted due to these attributes.

3. Advantages of Additive Manufacturing

3.1. Save Materials

Additive manufacturing is inherently referred to as "green production"[6]. Since materials are added layer by layer, only the necessary materials for the parts are utilized during the production process, resulting in minimal waste. Additionally, as previously mentioned, additive manufacturing can minimize the use of hazardous chemicals (such as cleaning solutions) and facilitate the use of recycled materials. This is in stark contrast to traditional subtractive manufacturing processes (like machining), where the required parts are carved out of a block, often leaving behind scraps (including oily cutting fluids) as waste. Notably, for metal materials, waste reduction is particularly significant.

3.2. High Efficiency

In traditional manufacturing, the price of a product is heavily influenced by the costs incurred during the assembly process, rather than the price of the individual parts themselves. When employing 3D printing technology for production, the feature of printing products in a single pass significantly reduces the complexity of production, thereby greatly simplifying the assembly process. Furthermore, it effectively cuts down on production costs while ensuring a reduction in manufacturing errors and mistakes [7].

3.3. Printing Complex Shapes

3D printing boasts a unique advantage in creating intricate shapes that are unachievable through any other method. Essentially, the additive manufacturing process enables designers to strategically place materials precisely where they are needed. Inspired by nature's wonders, such as coral, wood, and bone, designers can now craft honeycomb-like materials - robust and rigid structures that remain lightweight. Conversely, while the manufacturing industry often benefits from economies of scale, where producing a larger quantity of products can lead to cost savings, 3D printing disrupts this norm by offering equal cost efficiency for both identical and diverse product batches. Hence, variety without additional cost is a pivotal characteristic of 3D printing. [3] Notably, the term "free" in this context does not imply zero cost differences between printing identical and varying products; rather, it signifies the ability to offer diverse product lines without incurring additional expenses. Furthermore, 3D printing facilitates personalized customization, allowing users to effortlessly and efficiently incorporate their preferred text, patterns, and colours onto products.

4. Technological Progress

In recent years, additive manufacturing technology has significantly advanced in numerous high-end manufacturing sectors.

In the food industry, 3D food printing has emerged as a novel technology, enabling the creation of intricate structures and shapes by mixing and processing specific materials through layer-by-layer deposition based directly on computer-aided design data. This technology also allows for the introduction of intriguing designs into food, transforming its appearance. For instance, it can alter the shape of pasta, transforming traditional thin noodles into macaroni.

Another industry that heavily utilizes 3D printing technology is the aerospace industry, as previously mentioned. In recent years, the maturity of 3D printing technology in aerospace has grown substantially, enabling its widespread application in the production of aerospace components, including engine spare parts. [6] Given that engine components are prone to damage and require frequent replacement, leveraging 3D printing technology to manufacture spare parts offers an effective solution, minimizing material waste and cost.

In the automotive industry, 3D printing technology has sparked innovations, enabling the rapid creation of lighter and more intricate structures. For example, Local Motors printed the first 3D-printed electric vehicle in 2014. Beyond automobiles, Local Motors has broadened the application of 3D printing technology by manufacturing the OLLI, an unmanned, electric, recyclable, and highly intelligent 3D-printed bus. Additionally, Ford leads the way in 3D printing technology adoption, employing it for prototype and engine part production. BMW, too, utilizes 3D printing technology to manufacture hand tools for automotive testing and assembly. In 2017, Audi collaborated with SLM Solution Group AG to produce spare parts and prototypes [2].

In the electronics and electrical industry, the application of 3D printing has become increasingly widespread and sophisticated. It is now extensively utilized in the production of structural electronic devices, including active electronic materials, electrodes, and devices that leverage the embedding of conductors within 3D printing structures to achieve large-scale customization and adaptive designs. The fused deposition modelling process within 3D printing technology offers a cost-effective and time-efficient means for large-scale electrode material production. Furthermore, the 3D printing process for 3D electrodes is fully automated, ensuring high precision, and can complete the printing of eight electrodes in just 30 minutes [2].

3D printing has also ventured into the realm of construction, with numerous explorations undertaken in recent years. The printing of low-rise buildings has steadily matured and is being increasingly adopted. However, challenges persist in the construction of high-rise buildings, necessitating advancements in both materials and material printing techniques [8].

5. Future Trends and Research Directions

5.1. Predictions on Future Trends in Additive Manufacturing within Mechanical Engineering

With the advancement of additive manufacturing technology in recent years, countries worldwide are actively researching additive manufacturing technology for titanium alloys, expecting it to be applied in numerous engineering projects [9]. Notably in engineering materials, titanium alloy additive manufacturing technology holds the greatest potential for future applicability, potentially even fully replacing traditional titanium alloy materials. Currently, titanium alloy additive manufacturing has found its way into aerospace, defence, and other engineering sectors, but its future scope of application will undoubtedly extend far beyond these realms. The development of titanium alloy additive manufacturing technology is still in its infancy, requiring continuous refinement and improvement through the concerted efforts of research institutes and various organizations. This technology is bound to evolve towards greater production complexity, precision, scale, and cost-effectiveness [9]. Simultaneously, additive manufacturing technology will be adopted in a broader spectrum of mechanical engineering fields, facilitating rapid production, significantly accelerating the growth of China's manufacturing industry, and bolstering the country's economic development. Shifting from mass production to personalized customization, additive manufacturing plays a pivotal role. For instance, Haier now enables its designers and users to collaborate through online interaction for personalized product design, though they still face manufacturing challenges. Thus, in the future,

additive manufacturing technology has the potential to emerge as a viable alternative to traditional manufacturing methods.

5.2. Potential Technological Breakthroughs and Emerging Application Areas

The integration of additive manufacturing technology and nanomaterials holds the potential to surmount fundamental material and design constraints that currently impede additive manufacturing engineers and designers. Nanotechnology introduces a novel approach to additive manufacturing, augmenting existing techniques and facilitating the creation of novel nanocomposites [10]. The convergence of additive manufacturing and nanotechnology presents myriad opportunities. Incorporating metal nanoparticles typically leads to lower sintering temperatures, enhanced part density, and mitigated shrinkage and deformation of printed components. Furthermore, embedding metal nanoparticles within polymer materials elevates the conductivity of the manufactured products. The incorporation of carbon nanotubes into the printing medium offers a promising route to bolster the mechanical properties and elevate both the electrical and thermal conductivity of the final components. Nevertheless, when nanoparticles are utilized in conjunction with their respective printing media, the corresponding additive manufacturing technologies exhibit certain limitations. In essence, while the fusion of additive manufacturing technology and nanotechnology promises numerous prospects for the future, extensive research endeavours remain indispensable [10]. Likewise, the integration of additive manufacturing technology with bioengineering technology can further propel the horizons of additive manufacturing. The geometric flexibility offered by additive manufacturing enables the fabrication of optimized scaffolds that foster cell growth while preserving structural integrity, potentially facilitating the direct printing of human tissues in the future. These 'bioprinters' could ultimately revolutionize the printing of replacement organs for transplantation.

6. Summary

This paper provides a comprehensive overview of additive manufacturing technology and explores its potential development trajectories and application domains in the future. Presently, additive manufacturing technology has matured significantly, making its mark in various manufacturing sectors and bestowing numerous benefits upon individuals, corporations, and governments alike. The future of additive manufacturing technology appears promising, as researchers can embark on exploring and experimenting with the integration of this technology with others, thereby unlocking a myriad of new possibilities.

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