Research Applications of 3D Printing in Biosensors

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Abstract. With the development of society, the concerns of the public have shifted to the aspects of physical health and environmental protection. This leads to a huge demand for biosensors. At the same time, 3D printing has been improving for several years. In this review, the Various categories of 3D printing and their accessibility on biosensors are discussed. There are 7 main types of 3D printing. When each type of technique is applied to biosensors, advantages and disadvantages will emerge. In the final, vat photopolymerization is found to be the most suitable way to apply mature biosensor solutions, which are for the commercial market. And material extrusion and material jetting are good ways to help experimenters build simple sensor prototypes in the early stages of research and development. By aligning 3D printing methodologies with biosensor design goals, this review contributes to accelerating innovation in healthcare, environmental monitoring, and point-of-care diagnostics, addressing pressing global challenges.

Keywords: 3D printing, biosensors, printing materials, biomaterials.

1. Introduction

Nowadays, the need for 3D printing has risen rapidly in recent years. Especially in the production of objects that have complex internal structures and require high printing precision. More products can be manufactured by 3D printing, which cannot be manufactured easily as well as efficient in ordinary machines. With the help of computer-aided design (CAD)and computed tomography (CT) scanning, 3D printing can contribute to the research and manufacture of biosensors [1]. The biosensor is generally defined as a device that has one or more functions that include being a bioreceptor which detects particles in organisms, a transducer which translates the bio-signal into a digital output and an amplifier, which makes the detected signal easier to read and analyze [2]. The biosensors have been used in environmental control, food industry and the agriculture industries etc. [3]. However, when 3D printing technology is projected in biosensors, sensors that can apply on the human body, detect and prevent disease are desired and have attracted increasing research attention.

Different types of 3D printing and each trait of them will be researched. The printing materials fit for each printing method are discussed.

2. The Main Classifications of 3D Printing Techniques and Their Compatibility for Biosensors

According to ISO/ASTM 52900 standards, 3D printing processes are classified into seven major categories [4]: binder jetting (BJ), directed energy deposition (DED), material extrusion (ME), material jetting (MJ), powder bed fusion (PBF), sheet lamination (SL) and vat photopolymerization (VP) [1], as shown in figure 1.

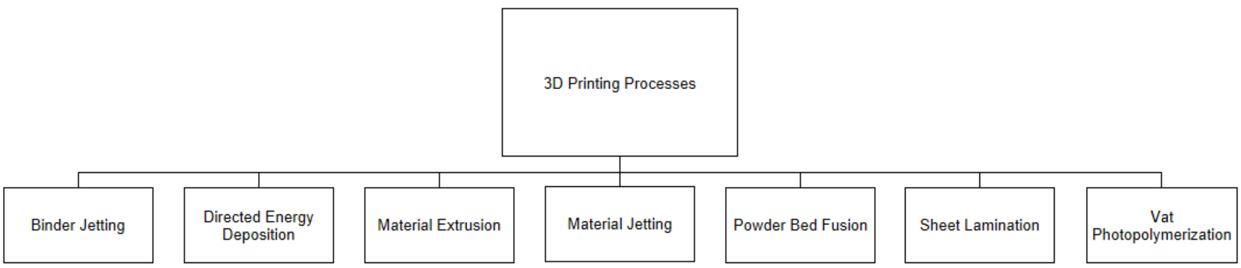

Figure 1. 3D Printing Processes

2.1. Binder Jetting

In this method, a binder (which is normally a polymeric liquid) is used to bond the powdered material, which is contained in a box. The powder, which contacts the binder, is shaped then the item printed can be moved from the box. The unbonded powder would fall back into the box. This method was first invented at a university. After progressive development, various materials can be printed: metals, ceramics, and polymers etc [5].

For ceramic materials, these can be used to build interior support and enclosure for biosensors. Ceramics can ensure structural strength, and at the same time, ceramics have high biocompatibility [6]. Bioceramics have been researched in recent years, which are commonly used for orthodontics [6]. The feasibility of bioceramics in 3D printing necessitates a comprehensive investigation due to their unique advantages in biomedical applications.

In terms of commercialization, binder jetting is considered a low-cost method because of the unused powdered material that can be recycled. In this case, the concept of environmental could be complied with and the image for companies in the minds of customers would be improved. While the post-processing steps (curing and densification) are necessary. This might increase the complexity of production slightly.

The advantages for BJ include material recyclability, cost-effectiveness, and multi-material compatibility. Ceramic materials are kinds of printing material which have high biocompatibility, these materials are suitable for manufacturing biosensor enclosures and structural supports. However, post-processing steps are required to enhance mechanical integrity. In addition, BJ is viable for environmentally sustainable commercial production.

2.2. Directed Energy Deposition

It is a method that uses lasers (a kind of thermal energy can be used) to melt the powdered metal material [7]. However, it is different from the powder bed fusion (PBF), the powdered material is fed by a wire or a cable [8, 9].

The method is commonly used for manufacturing large metal parts (such as a cargo ship's oars). For biosensors, they usually do not need huge metal components. Thus, DED might not be the most suitable method for making a biosensor. The application of metals in biosensors is mainly researched in electrodes and as a reactant that can react and detect certain particles in cells.

Gold (Au) and silver (Ag) are preferred to use as electrode materials in biosensors because of their conductivity and ease of biomolecule immobilization. While the accessibility of whether Au and Ag can be used as printing materials should be discussed and researched. On one hand, the melting points for Au (about 1064°C) and Ag (about 962°C) differentiate from the common printing material for DED, such as aluminum (about 660°C). The temperature ranges during printing should be considered when printing material is mixed with different metal powders.

On another hand, because of the ductility of Au and Ag, the layers that have been printed might deform. This may cause printing dislocation on upper layers. In the whole-cell biosensors, some heavy metals are required (such as mercury). The heavy metals may be toxic and cause problems for life and health when they need to be printed in certain shapes (such as a small square) if the printing machine is not enclosed or cannot handle toxic gases.

DED exhibits limited applicability because DED is too dependent on material feasibility. It is hard to find a suitable material for biosensor printing.

2.3. Material Extrusion and Material Jetting

These two methods are used to print layer by layer, and polymers are the main material for printing. For material extrusion, the polymer materials are fed and heated in a liquefier. The solid polymers melt and become a viscous liquid. Then the molten polymers are extruded to print. For material jetting, the liquid photopolymers are extruded. Then the UV lights can help polymers to cure and build one of the layers.

ME and MJ are methods to print by extruding materials and building in layers, which is one of the lowest-cost ways to print. These two methods are commonly used on civilian 3D printers. It is easy and quick to print objects in houses or schools, which helps test and refine biosensor prototypes.

For MJ, the thinner layers increase the accessibility of printing biosensors in microscopic size, also reducing the jagged edges and surfaces, which may cause damage to skin and lead to an uncomfortable sensation for the creature.

In addition, the polymers usually have low densities, and biosensors which printed by polymers have lower masses and are easier to carry. However, structural strength is not ideal for polymer biosensors. External forces may cause structural damage to the printed components in biosensors.

2.4. Powder Bed Fusion

This method uses thermal energy to melt the powdered materials, which are similar to the DED. The PBF is to build layer by layer, which is different from the DED [10]. The three main techniques are selective laser melting (SLM), selective laser sintering (SLS), and electron beam melting (EBM) [10].

PBF might not be the most suitable method for making a biosensor, as well as the DED, because of the limitations of metal applications in biosensors, which have been mentioned in 2.2. Material toxicity and expensive equipment cost need to be considered, which may limit suitability for biosensor manufacturing by using PBF.

2.5. Sheet Lamination

SL is a kind of additive manufacturing technique (which includes ME, MJ and PBF etc.) [11]. Many sheets of material are pressed together during the process of printing [11].

SL is not suitable for printed protective cases or the bracket for biosensors, while it is one of the good ways to fix a flaky detector (such as an electrode sheet) on a broad.

2.6. Vat Photopolymerization

VP is a method that uses UV lights to cure liquid photopolymers, similar to the MJ. But for VP, liquid photopolymers are put in a huge container and lights selectively shine on the photopolymers to build layers (VP is also a kind of additive manufacturing process). After printing is completed, the model is removed from the platform, and then the liquid photopolymers on the model.

Vat photopolymerization is one of the best ways to print the main body bracket of the biosensors. Compared to other methods, the objects printed by Vat photopolymerization have a smoother surface and are able to be printed with higher internal complexity.

In recent years, biocompatible resin has been researched and applied in the medical field. Thus, biocompatible resin can be a ideal printing material for Vat photopolymerization to print biosensors because of its high biocompatibility.

3. Challenges and Future

Materials that have high biocompatibility should be developed. Most of them remain in the laboratory stage. Furthermore, nanorobots are widely needed to perform specific tasks in blood vessels, and nanorobots may contain biosensors. This requires higher precision and resolution for printing techniques. Then, for scalability issues, it takes too much time to print only one piece of an object. The efficacy of production should be improved unless the products using 3D printing are hard to commercialize with a high possibility.

4D printing is one of the newest printing techniques. 4D printing is fabricating an object using 3D printing, and the object can change its shape over time because of the special material. Thus, this kind of material should be researched further in the future. 4D materials can change shape when specific surroundings change (such as temperature). This is useful for biosensors to detect signals with higher accuracy.

4. Conclusion

In conclusion, 3D printing is an ideal way to produce biosensors because 3D printing can fit the requirements of biosensors needing to be in a certain shape. Vat photopolymerization is one of the best ways to use due to its high biocompatibility in printing material and high accessibility in the complexity of printing. Material extrusion and material jetting are also suitable ways to assist in printing components at the initial stage of research for biosensors. This research is hoped to help the researchers analyze and select suitable 3D printing methods for their projects on biosensors. For future Perspectives, the accessibility of the directed energy deposition method to print a nanoporous electrode, which can increase the efficiency of electrode, should be researched. And more printing materials that with high biocompatibility need to be developed, such as bioceramics and biopolymers. The precision of 3D printing needs to be improved, which can print biosensors and micro robots in the nanoscales. The development of biosensors helps monitor human health, prevent diseases, and improve life of well-being.

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