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Original Research Article

Application and Innovation of 3D Printing in Medical Equipment Maintenance

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ABSTRACT

With the continuous progress of technology, 3D printing technology is setting off a revolution in medical equipment maintenance. The traditional supply chain and manufacturing process often lead to long maintenance times and high medical equipment costs. However, after the introduction of 3D printing technology, medical equipment maintenance will usher in a brand-new solution. Through 3D printing, medical institutions can manufacture the required parts independently, without relying on suppliers' delivery, thus greatly shortening the maintenance time. In addition, 3D printing can also be customized and optimized according to specific needs, improving the functionality and performance of medical equipment. Therefore, the application innovation of 3D printing in medical equipment maintenance will bring great potential and opportunities to the medical industry and provide better medical services for patients. This innovation will make medical equipment maintenance faster, more economical, and efficient, and meet individual needs, bringing unprecedented development opportunities for the medical industry.

Keywords—*3D printing, Medical equipment, Maintenance, Innovate.*

INTRODUCTION

3D printing plays an important role in medical equipment, providing a cost-effective solution for hospitals and medical institutions to replace some special structural plastic parts.[1] By using 3D printing technology, we quickly created high-quality customized alternatives to suit the specific needs of medical devices, resulting in cost savings for hospitals. 3D printing has many advantages over conventional manufacturing methods. First, it enables complex structures to be printed in an integrated manner without additional assembly work. This not only reduces the manufacturing time but also improves the reliability and stability of the product. Second, 3D printing also offers a more flexible material selection. We can select different kinds of plastic materials to print according to medical device use environment and functional requirements. By doing so, we can ensure that medical devices have the durability, corrosion resistance, and high-temperature resistance to meet various complex medical needs.[2] Therefore, the application innovation of 3D printing in medical equipment maintenance was further analyzed in this study.

TECHNOLOGY DEVELOPMENT AND APPLICATION STATUS OF 3D PRINTING IN THE MEDICAL INDUSTRY

Principle and Development of 3D Printing Technology

3D printing (three-dimensional printing) is a technology for manufacturing three-dimensional objects by stacking specific materials layer by layer. Compared with the traditional "subtractive manufacturing process", 3D printing is an "additive manufacturing process". Its working principle is based on the core concept of "layer-by-layer stacking." It can be understood that the digital model is divided into a series of ordered two-dimensional sections (slices) according to the Z axis (perpendicular to the horizontal plane), and these sections are stacked layer by layer using specific materials, finally forming a three-dimensional entity.

3D Printing Process

(1) Three-dimensional model design stage: First, a three-dimensional digital model must be created or scanned using CAD-Computer Aided Design software or other 3D modeling tools.

(2) Model data optimization stage: No matter in the process of scanning entities to obtain 3D point cloud reprocessing modeling or direct entity modeling, certain supporting structures can be added to maintain the shape and stability of printed objects and the supporting structures can be removed after printing.

(3) Section processing stage: The three-dimensional model is imported into the 3D printing software, which will segment the model into extremely thin two-dimensional sections, commonly known as "sections", which will guide the 3D printer to build objects layer by layer.

(4) Layer-by-layer stacking stage: the 3D printer uses specific materials (such as plastic, metal powder, and ceramic) to stack layer by layer according to the slice information. After each layer is stacked, the printhead moves to the next layer and repeats the stacking process until the entire object is built.

Key Technologies

Material selection. 3D printing uses various materials, including plastic (such as ABS, PLA), metal powder, ceramic, glass, etc., and different materials have different physical and chemical properties suitable for different application scenarios. In the maintenance of medical equipment, it is very important to select the appropriate materials, which need to have the characteristics of durability, biocompatibility, and mechanical properties to ensure that the equipment, after maintenance, can run normally and meet the medical standards. First, medical institutions can work with professional material suppliers to jointly evaluate and test the performance of different materials to find materials suitable for medical equipment maintenance. Second, medical institutions can conduct laboratory tests and clinical trials to assess different materials' durability, biocompatibility, and mechanical properties. Through independent research development and testing, medical institutions can ensure that the selected materials meet the medical industry' s requirements and maintenance equipment needs. Third, medical institutions should establish strict quality control procedures, including material procurement, inspection, and verification.[3] Fourthly, a feedback mechanism is established to timely collect and analyze the performance data of the equipment after maintenance and make adjustments and improvements according to the data results, to promote medical institutions to continuously optimize the material selection and quality control procedures and improve the effectiveness and reliability of the equipment maintenance.

Printing accuracy. The accuracy of 3D printing depends on several factors, including the printer's design, the slicing process' s accuracy, the material's nature, and so on. In the 3D printing process, medical institutions can take measures to establish an effective quality control process and improve the quality and reliability of printed parts. First of all, medical institutions can determine the optimal printing temperature, printing speed, height, and other parameters through experiments and tests. The printing parameters of different materials and parts may differ, so they must be adjusted and optimized according to the specific situation. Optimizing the printing parameters can improve the surface quality, dimensional accuracy, and strength of parts. Secondly, before printing, medical institutions can use 3D modeling software to check the design documents to ensure no error in geometry and size and conduct finite element stress analysis under certain conditions. The printed parts are divided into a limited number of smaller elements. The analysis module applies each element' s appropriate physical conditions (such as load and boundary conditions). The analysis results can be reported, including information about the product stress distribution, safety factors, and shape variables, to ensure the intensity reliability of the printed parts. Thirdly, medical institutions can also track and trace the quality control process of each printed part by establishing detailed documents and records and reviewing and analyzing them when necessary. Finally, medical institutions should ensure that 3D printing equipment is in good working order, maintained, and calibrated according to the manufacturer's recommendations. Periodic maintenance and calibration can ensure the equipment' s stability and consistency and improve the printed parts' quality and reliability.

Application Status of 3D Printing in the Medical Industry

Implant Printing

Dental implants: 3D printing technology is introduced in dental restorations such as reseeding and the application in digital processing of dentures, thus obtaining the final product manufacturing materials with medical certification.

Orthopedic implants: 3D printing technology can produce more advanced and qualified implants and prostheses, which also increases the delivery speed of customized implants. From design to manufacturing a customized implant, it can be completed within 24h at the earliest.

Adjuvant Therapy

Rehabilitation devices: The US team of Mak-er worked with Stratasys, a 3D printing company, to make prosthetic limbs for a child for as little as $350, while conventional prosthetic limbs cost as much as $40,000. Artificial limbs need to be replaced many times during children' s growth. If traditional artificial limbs are purchased, it will burden families heavily.[4]

Teaching of anatomical model: When 2D images formed by X-ray films, MRI, and CT scans are used to study and simulate surgical anatomical structures, the guiding significance is low, while 3D printed models can provide more detailed, intuitive, and stereoscopic anatomical information due to the characteristics of high fidelity.[5]

Drug Research

Conventional manufacturing methods are unsuitable for producing individualized drugs and complex geometries, limiting the ability to produce customized dosage forms. The advantages of 3D printing of drugs include accurate drug size and dose control, high repeatability, and the ability to produce dosage forms with complex drug release characteristics. According to patients' age, weight, and disease severity, the development of personalized drugs through 3D printing can improve efficacy and reduce adverse reactions.[6, 7]

Biological Printing

A multidisciplinary research team from the University of Minnesota, Virginia Tech, the University of Maryland, Princeton University, and Johns Hopkins University has designed a custom-made nerve guide tube with 3D printing, which is filled with biochemical signals that can cause the growth of motor and sensory nerves to help the recovery of the sensory and motor functions of the damaged nerves.[8]

Maintenance of Medical Equipment

Xu et al.[9] conducted reverse modeling on the fractured syringe pump fitting through parametric modeling, conducted stress analysis and strengthening on the model, and finally made the replacement using the FDM process. Shen et al. [10] used the 3D scanner to obtain three-dimensional information on the damaged parts of the washing and disinfection machine and processed repair through software, finally making the available parts through a 3D printer.

Visual Teaching and Training

By presenting the internal structure and working principle of medical equipment in the form of the physical model, we can provide medical staff with a more intuitive and visual tool to help them better understand the use of equipment and maintenance procedures. First, through the 3D printing technology, we can make the physical models of medical equipment. These models can accurately display the internal structure and components of the equipment so that medical staff can understand the working principle of the equipment more clearly. Compared with traditional teaching methods, this visual approach is more vivid and intuitive, which helps to improve the learning effect. By observing and operating these models, medical staff can better understand the use of the equipment and operating procedures.[11] Secondly, 3D printing technology can also make a detachable model so that medical staff can understand the internal structure of the equipment in depth. They can disassemble the model and observe the position and function of each component better to understand the equipment's working principle and maintenance process. This hands-on participation can enhance medical staff's learning interest and participation and improve their understanding and mastery of the equipment. Finally, the models produced by 3D printing technology can also be used to simulate the actual operation. Medical staff can use these models to practice and be familiar with equipment and maintenance processes. This practical teaching method can help them master the skills and improve work efficiency and accuracy.[12]

Development Opportunities and Challenges of 3D Printing

Development Opportunities for 3D Printing

(1) Technological innovation and integration, combining 3D printing technology with advanced technologies such as artificial intelligence and big data will push it towards intelligence and automation and improve production efficiency and quality. The development of material science will promote the diversification of 3D printing materials so that more materials (such as metal, plastic, ceramic, etc.) can be used to make superior performance products.

(2) Growth of market demand. With the wide application of 3D printing technology in aerospace, automotive, medical, and other fields, the market demand will continue to grow. The advantages of 3D printing technology in personalized customization and complex structure manufacturing will promote its popularity in the consumer goods market.

(3) Policy support and promotion. Various governments have issued policies to support the development of 3D printing technology, including providing funds and establishing an innovation platform. 3D printing technology has been included in the national strategic emerging industry development plan, becoming an important force in promoting the transformation and upgrading of the manufacturing industry.

Challenges for 3D Printing

(1) Large-scale production cost. Although 3D printing technology has advantages in prototyping and small-scale production, it still faces the challenge of high cost in large-scale production. The high price of industrial-grade 3D

printing equipment and materials used and the limitations of processing methods and processing efficiency make it difficult to reduce the cost of large-scale production.

(2) Print quality and consistency. Minor errors that may occur during 3D printing, such as excessive or insufficient extrusion, can cause problems such as porosity, cracks, or deformation in the finished product. These defects not only waste resources but also increase the unpredictability of traditional manufacturing methods.

(3) Intellectual property protection. The popularity of 3D printing technology makes copying products easier and puts higher requirements for intellectual property protection. How to effectively protect the intellectual property rights of designers and manufacturers has become an urgent problem to be solved in the development of 3D printing technology.

(4) Technology and standard system. Currently, the scale of the 3D printing industry is limited, the degree of marketization is relatively limited, and the application cases of mass manufacturing are few. The corresponding application standard system still needs to be established and improved to promote the standardization and development of 3D printing technology.

ADVANTAGES OF 3D PRINTING IN MEDICAL EQUIPMENT MAINTENANCE

Rapid Manufacturing and Customization Capabilities

In the traditional maintenance process, we often need to wait for the supplier's delivery, which costs a lot of time. With 3D printing technology, medical institutions can immediately manufacture the required parts without waiting.[13] At the same time, 3D printing can also be customized according to the specific needs of the design to meet the personalized requirements of different devices.

Cost and Resource Savings

The traditional supply chain and manufacturing process need many intermediate links, which wastes time and a lot of resources. 3D printing technology can directly convert design into physical products, reducing the intermediate links, thus saving costs and resources.

Improve Equipment Maintenance Efficiency and Reduce Downtime

3D printing can improve equipment maintenance efficiency and reduce downtime. In the traditional maintenance process, we often need to wait for the supply or transportation of parts, which leads to prolonged equipment downtime.[14] However, with 3D printing technology, medical institutions can immediately manufacture the needed parts, dramatically reducing repair time and improving equipment availability.

APPLICATION INNOVATION OF 3D PRINTING IN MEDICAL EQUIPMENT MAINTENANCE

The existing modeling techniques can be divided into wireframe, surface, solid, assembly, parametric, feature, and other types according to their different usages.[15] In this study, Autodesk Inventor Professional 2019 was used to conduct solid modeling for the patient to monitor the protective shell (with handle). Solid modeling establishes a 3D solid model using basic voxel combination through collection operation and basic deformation operation. The generated solid model consists of a series of straight lines, arcs, points, and free curves, which describe the outline of the product.[16]

Modeling

Using vernier calipers to physically measure the exterior dimensions of the patient' s monitor and then use 3D modeling software to combine the measured dimensions with the parameters to design the protective shell of the monitor, taking into account the thermal expansion and contraction of the print material, the tolerance of the design is controlled at ± 0.03 mm (FDM fused deposition), and the modeling of the part is completed. The part is assembled in the Inventor software. See Figures 1–3.

Inventor Stress Analysis (Finite Element Analysis)

Stress analysis, *i.e.*, finite element analysis, converts an engineering system from a continuous system to a finite element system (discrete system) for solving and calculating engineering problems: The stress analysis environment in Inventor is dedicated to isotropic materials, such as metals, plastics, and glass; Stress analysis

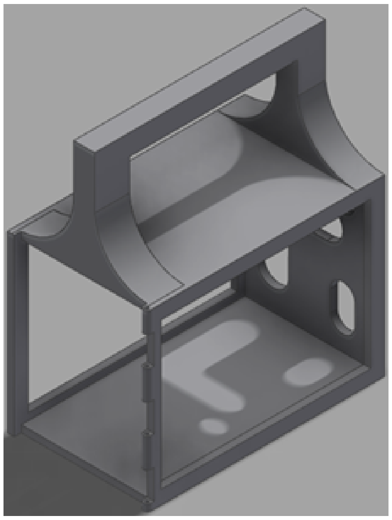

FIGURE 1. Model of protective case part 1 of monitor.

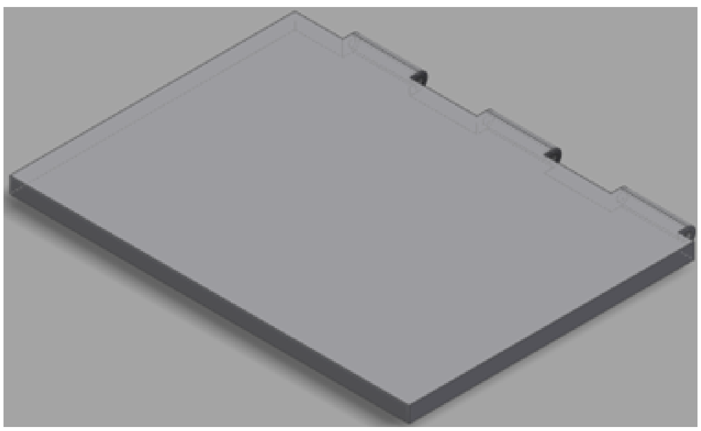

FIGURE 2. Model of protective shell part 2 of monitor.

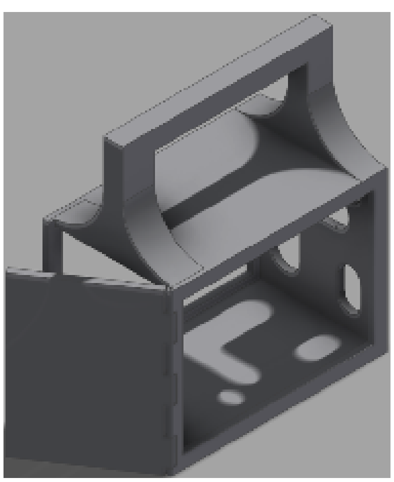

FIGURE 3. Assembly model of protective shell parts of monitor.

can find out the dangerous points, *i.e.*, the parts with stress concentration or strain concentration, which are often the potential positions of part failure. Optimization design, according to the results of the stress analysis, can be part or component design optimization, for example, by adjusting the thickness of the material, shape, or the layout of the reinforcement to reduce stress concentration and improve the structure strength; Validation design, in the product design stage, you can use stress analysis to verify the rationality of the design, through the simulation of the actual working environment of the force, you can predict the performance and life of the product.

(1) Specify the part as ABS material, as shown in Figure 4:

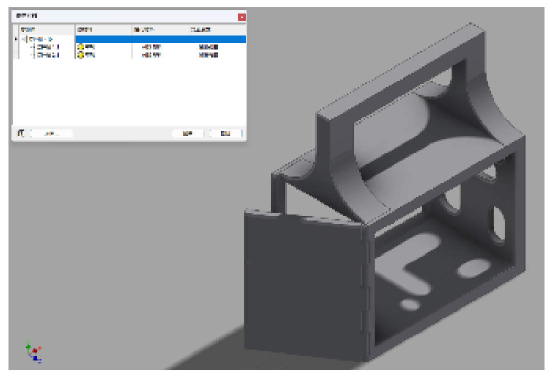

FIGURE 4. Specified part material.

(2) According to the actual use of parts, set constraints, as shown in Figure 5:

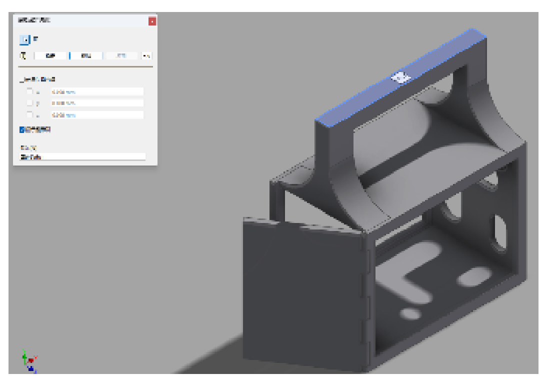

FIGURE 5. Setting constraints.

(3) Based on the actual use of the parts, set the load situation. The net weight of the monitor is about 4 KG, and the corresponding load is about 40 Newton (N), as shown in Figure 6:

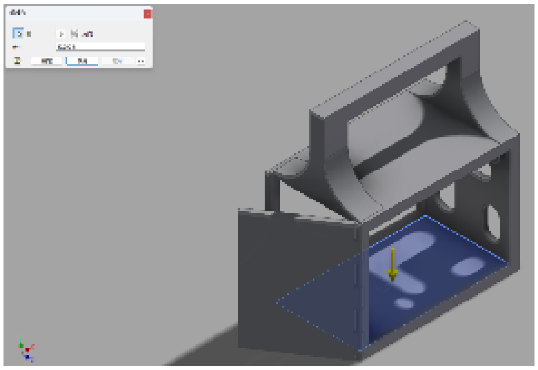

FIGURE 6. Setting load.

(4) Set the finite element analysis grid, the average element size is set to 0.05, as shown in Figure 7:

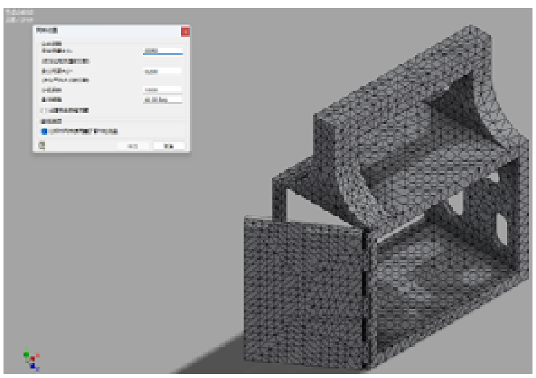

FIGURE 7. Setting finite element analysis grid.

(5) Running results, the maximum displacement of 0.1609 mm, as shown in Figure 8:

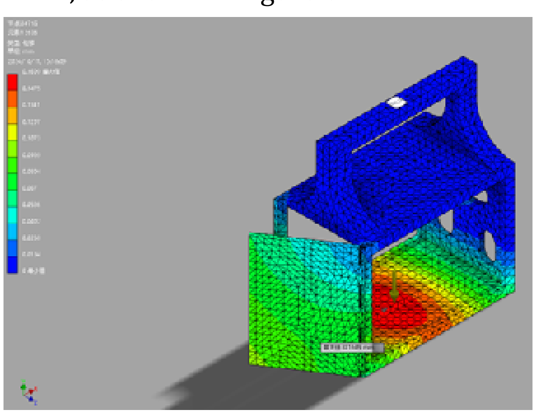

FIGURE 8. Maximum displacement.

(6) The minimum safety factor is 15, as shown in Figure 9:

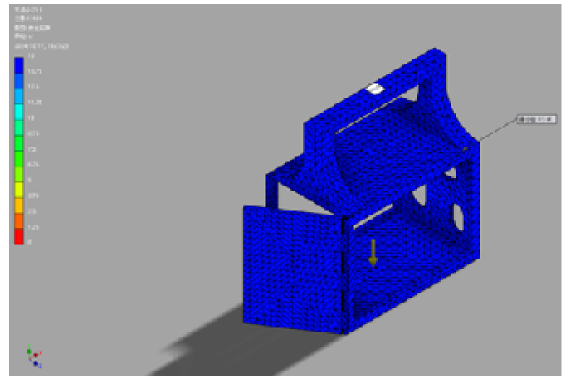

FIGURE 9. Minimum safety factor.

According to the Autodesk Support website,[17] the safety factor is the ratio of the allowable stress to the actual stress. A safety factor of 1 indicates that the stress is within the allowable limit, a safety factor of less than 1 indicates a possible failure and a safety factor greater than 1 indicates that the stress is within the allowable limit. The minimum safety factor in this design is 15, and a safety factor greater than 1 indicates that the design is reasonable.

Part Printing

Slicing Software

Use slicing software to load the model file with the .STL format and conduct slicing operation. slicing is to cut the 3D model into a series of slices, and each slice represents the part that the printer needs to print layer by layer during the printing process.

Set Print Parameters

In the slicing software, you need to set the printing parameters, such as printing temperature, filling density, layer thickness, shell, etc. The settings of these parameters need to be adjusted according to the printer model, printing materials, and printing requirements.

Export Print File

After setting the parameters, export the sliced file to a format that the printer recognizes.

Start Printing

Transfer the exported print file to the 3D printer, prepare the print material, and start the printer, and the printer will print the model layer by layer according to the parameters and paths set in the slicing software.

Aftertreatment

The surface of the printed model may be rough and needs to be ground and polished. You can use sandpaper, polishing paste, and other grinding tools to make the model surface smoother, as shown in Figure 10.

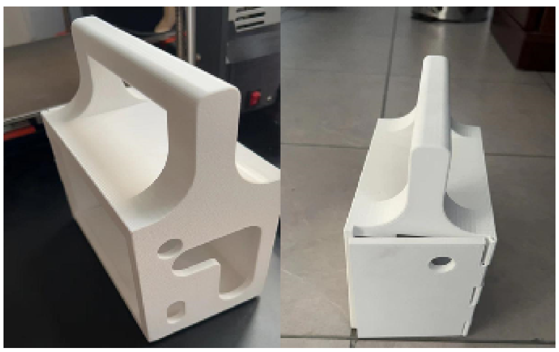

FIGURE 10. The protective case of monitor.

CONCLUSION

In actual maintenance, the original cost of spare parts is much higher than 3D printing, and the purchase of original spare parts costs about 300 Yuan, while the cost of 3D printing is under 50 Yuan; Parts usually take one week to arrive, while 3D printing can be done in one day, saving maintenance costs and reducing maintenance time.

In this study, the significant advantages of 3D printing technology in terms of speed, precision, and cost control are demonstrated through the manufacturing example of the protective shell of the monitor, which is especially suitable for the rapid manufacturing of single spare parts required for the maintenance and later improvement of medical devices. Currently, 3D printing technology is still in the preliminary application stage in hospital equipment maintenance. This research aims to deeply explore this technology, optimize the design of 3D models, improve production efficiency, and ensure that it can quickly respond to the needs of clinical departments to maximize the social benefits of medical equipment.

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