Review

Computation

3D Printing Model Optimization

Richard Alam*
Digital Life Inc., Austin, TX 78653, USA
*: All correspondence should be sent to: Mr. Richard Alam.
Author's Contact: Richard Alam, MSc, E-mail: richard.alam@digitlife.net
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The instantiation of 3D models has become much more convenient attributable to the development of 3D printing technology, but processing digital geometry now faces new difficulties. The model optimization inspired by 3D printing is summarized in this paper from the two processes of model creation and printing in order to be able to print out models that have accomplished some defined functionalities.

Keywords: 3D Printing; Modeling; Design Optimization; Printing Optimization

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A MODERN manufacturing technique based on three-dimensional model data is called 3D printing. It is also known as "additive manufacturing" (AM) because it produces objects by adding materials rather than the conventional method of depleting resources (1). Due to this innovative manufacturing technique, 3D printing is now widely usable and can be utilized to create three-dimensional objects in practically any shape. This has also emerged as 3D printing's greatest benefit.

The 3D printing market has grown quickly in recent years, and new printing techniques and tools are constantly being created. The design and manufacture of customized items are thought to benefit from the advancements made possible by 3D printing technology (2). In addition, the advancement of 3D printing technology helps processing digital geometry has introduced additional difficulties. Researchers have conducted a number of studies using the geometrical properties of 3D models in combination with the process of discovering and optimizing the instantiation model of 3D printing and have attracted increasing amounts of attention (3). Researchers focus more on the geometric resemblance between the 3D model and the entity during the conventional modeling method. The ease of instantiating the model has increased with the proliferation of 3D printers. Researchers are now looking into ways to speed up and reduce the cost of this process by printing instantiated models that can perform a specified set of functions.

This paper will not go into great length on the history of 3D printing technology development or the current state of its research because that is not what it is about. It is important to note that, related geometric computing based on their unique characteristics is to analyze the problem's history and its function throughout the entire instantiation process in an effort to motivate readers to identify new research questions.

Model Design Optimization

The theoretical ability of the 3D models produced by conventional modeling to obtain things directly through 3D printers is made possible by the technology's broad applicability. The 3D-printed objects could be readily breakable or unable to fulfill specific functional needs, like stable standing. As a result, researchers change current models to improve the design of static 3D models. Furthermore, the advancement of 3D printing offers dynamic models. The production of sintering is quite convenient, so research on the creation of printed dynamic models has also gained a lot of attention.

Static Model

The most basic need for a static instantiation model is structural stability, which means that the object is not easily broken or damaged during the printing process or after completion. The researchers conducted a printability test on the model to ensure this property of the model. The over-detailed part of the model is the key to printability and developed a number of corresponding judgment criteria before providing the first automatic analysis model printability algorithm; however, they did not provide a solution to improve the model's printability (4). Following that, Nelaturi et al. improved it in terms of analysis accuracy and proposed a local thickening correction approach (5). Stava et al. recognized the weak structure by measuring the model's self-weight and potential stress sites when it was picked up and then altered the model as little as possible by adding pillars, local thickening, and internal digging, among other things (6). Furthermore, Umetani et al. investigated structural strength by examining force information on the section plane in a particular direction (7). The methods for analyzing printability and structural stability discussed above are based on for the study of the physical structure of the model's external force and its own gravity, but the forecast of the external force is frequently not very accurate, reducing the authenticity and trustworthiness of their analysis conclusions. Modal analysis is the main technology. Nevertheless, this is due to the limitations of their assumptions, as the proposed algorithm only initially evaluates the linear elasticity of the material and does not completely analyze the material's numerous properties.

Balance is another general criterion for static models, but if a model is printed directly, it may lose balance due to an unstable center of gravity. Prévost et al. proposed an interactive model body (8). Modifications that allow a model to stand or hang stably in a certain way are permitted alterations, which include deforming the model's surface and boring holes in the model. To make the model spin like a top or yo-yo, Bächer et al. modified the mass distribution by excavating holes in the model body to keep the model stable during rotation (9). Yamanaka and coworkers altered the model's underlying structure to ensure that the mass distribution met the predetermined predictions (10). This field of study is being researched. Typically, the optimum density distribution of the model is first assessed to meet a certain functional need under research, and then the requirements are accomplished by modifying the material distribution inside the model and gently deforming the shape of the model. Aside from models with specific requirements, new 3D printing modeling approaches have emerged, such as sensible furniture model design, geometric decoration design, and flat-panel assembly model design. Furthermore, because design and manufacturing typically necessitate numerous repeated tests to get the ideal model and object, quickly printing out the approximate model design to examine the current existing difficulties can significantly speed up the design modification progress.

Dynamic Model

The dynamic model known as the "articulated model" is one that is utilized frequently in computer animation. The traditional articulated model, on the other hand, is typically unable to be produced directly as the input of a 3D printer, so how to create a model based on the available data The lack of a joint model that can be printed out directly has emerged as a major problem. Böher et al. automatically transform the skinned mesh, which contains surface geometric information and internal bone information, into a single joint that can be printed (11). Calì et al centered on the design of various joint structures (12). Using user input, they built comparable joint models for a given common static mesh. In a similar vein, it is an entire file that can be printed straight away without assembly. The design of the joint structure and how to arrange these joints in the input model so that the finished model may move freely are the key areas of attention in this kind of research.

The joint model can be placed in various poses by manipulating the joints, and the mechanical model can further animate the model by modifying the motion of the gears. One after another, mechanical toys, robots, mechanical cartoons, and other creations have come to fruition and can be produced swiftly using 3D printing technology. The mechanical model's design is based on the specifications of the initial input for the finished animation, and it chooses and assembles the right pieces from the library of pre-generated parts in order for the final model to fully satisfy the input's specifications for the animation. The advancement of 3D printing technology has also sparked the production of other intriguing dynamic models, as demonstrated by Zhou et al., who were able to fold a voxelized model into a cube by optimizing the distribution of joint types among them and the setting of the folding path (13). The interactive tool of Megaro et al. allowed users to create dynamic models resembling puppets in a shadow play (14).

Printing Process Optimization

The finished 3D model will be fed into the 3D printer for initial manufacturing. Typically, the model is expressed as a 3D surface mesh, but 3D printing requires a solid model, so the first step is to convert the surface mesh to a solid model. After determining the printing direction, the solid model must be cut into a layer structure perpendicular to the printing direction, and the entire model is printed by stacking and accumulating layers by layers. The next sections will go over the issues that have arisen during the various stages of printing. The optimization challenges are introduced briefly to the corresponding researchers.

Capacity Limitation

Every 3D printer has a maximum printable volume; thus, it is possible that before printing even begins, the machine in use will not be able to accept the model being printed. The supplied model will be automatically cut and printed separately for this issue. Several algorithms for reassembling the original model have been put forth (15). All of these algorithms employ plane cutting, and connectors are created and spread across the cutting surface to allow for flexible part assembly. Luo et al. considered printability, structural stability, ease of assembly, aesthetic aspects, and other information in the cutting process in comparison to the prior work, and the number of separated blocks was also reduced (16). It is practical to restrict the model's plane cutting. The model segmentation problem is changed into the challenge of locating the ideal BSP tree by the addition of connectors, and the beam search technique then resolves this problem.

Breaking up the 3D model into interlocking sections addresses the issue that connectors sometimes cannot give enough structural assurances between parts and are easily destroyed during shipping or assembly. This interlocking technique gives the combined model exceptional stability and guarantees that the surface of each segmented model is smooth. This segmentation technique, however, is unable to satisfy both the requirements for aesthetic traits and ease of assembly.

Print Entity

The final grid is typically considered to be printed solid when evaluating the model's printability and altering the model to obtain additional useful features (except for the hollowed-out part in the modification process). Yet, most 3D printers will sparingly fill the body of the object with a structure that is looser than the surface in order to conserve printing materials and time. Unfortunately, the built-in software's sparse filling feature frequently falls short of what users are looking for in terms of time and resources; hence several academics have suggested alternative ways to convert 3D surface meshes into printable things.

In order to reduce the volume of the stated item and ensure that the printed object meets the necessary physical strength, stress stability, self-balance, and printability requirements, Wang et al. expressed the model as a very thin skin with an interior stiff frame structure (17). As the interior framework of the model, the honeycomb construction was used to assure the model's strength while minimizing material loss. These two works' primary contribution is their examination of self-stabilizing systems and their introduced successfully into the 3D printing process. Use a self-stabilizing structure to approximate the model, which significantly lowers the amount of material needed during printing while maintaining the stability of the structure. The force transmission path is maintained throughout the structural optimization process in order to attain structural geometry and objects. The method of gradually removing invalid or underutilized internal elements could reduce the printing volume. Because Vanek et al. did not begin with the self-stabilizing structure, the model's stability was compromised (18). Given the factors, they are more concerned with time and resource conservation. They directly reflect the model using the surface thin layer, which is separated, stacked, and printed all at once to further reduce printing time and costs.

Hierarchical Approach

The model body is equally layered along the chosen printing direction according to the printing accuracy in the standard 3D printing procedure, meaning that each layer has the same thickness. In reality, the best layer thickness will vary since the model's fineness varies in different regions of the model. The layering approach can be optimized to some extent to increase printing efficiency. The geometric approximation between the input model and the printed model is the major focus. After deciding on an appropriate printing direction, adaptive segmentation under the assumption was suggested that the model's prominent characteristics will be preserved (20). Layer algorithms, or layer structures with various thicknesses, are chosen in various regions based on the features. This adaptive layering algorithm's conspicuous features are preserved, and the important technological advancement is to turn it into a sparse optimization problem with constraints. The model can also be separated into blocks based on the analysis of the prominent features, and each block can be adaptively stratified to further reduce printing time.

Printing Materials

Multiple-material 3D printers are an inevitable trend in hardware development, even if the majority of low-end 3D printers now only have one nozzle and support a single material. This is because more items are comprised of several materials. Many goods are formally introduced. It is more natural for users to provide the material and aesthetic effects that the model wishes to achieve rather than the exact combination of materials when dealing with models that need various materials for printing. A focus of study for multi-material 3D printers is how to combine a variety of different basic materials to achieve the desired effect. The layering of various materials was optimized by Bickel and coworkers so that the final printed model can produce the required result—the resultant deformation after being hit by a specific external force (21). By combining simple materials, Hašan et al. sought to achieve the optimal surface scattering effect (22). In order to combine the aforementioned procedures, Chen et al. introduced the Spec2Fab algorithm framework to handle multiple material synthesis problems with various goals, based on the novel description of material space and the optimization process data structure (23). Another programmable pipeline approach called OpenFab was suggested by Vidimče to address several issues with material synthesis (24). They allow users to specify the specifications directly and properly for the geometry of the final printed model and the properties of the material, unlike Spec2Fab. Also, studies on the more popular low-end 3D printers with two nozzles have been conducted to reduce interpenetration between the two materials and print a specific texture image on the model's surface.

Support Structure

The studies described above are generally applicable to different kinds of 3D printers. Because of their low cost and ease of use, fused deposition modeling (FDM) 3D printers are preferred by both individual users and educational institutions. As a result, a lot of study is being done on this kind of 3D printer. The main drawback of this kind of printer is that in order to attach the suspended structures, extra support structures must be printed during printing. Moreover, they support It wastes resources and time on the one hand, and after printing is finished, these support materials must be physically removed from the model. What's worse is that the printed model can be damaged in the removal process because of how tough it is to remove them because of how tightly they are attached to one another. As a result, the key to maximizing this kind of printing technology is to minimize the need for support materials, and the techniques employed in previous research may essentially be split into two groups.

The first type of technique involves altering the support structure while leaving the original model untouched to save materials for the support structure itself. Currently, the support structure produced by the 3D printer's software is often vertically attached to the suspended part and the object immediately below it. The MakerBot Replicator 3D printer includes a support structure that was created with software in part. It is clear that this kind of support system is not ideal because it will require far more resources than the model actually requires. A stick-like structure can be used to connect the suspended points with the closest point on the grid or on the ground in order to strengthen the support structure by first identifying the suspended points. In addition, automatic support structure rod and addition process are also involved modifying the support bar's precise structure to improve its stability and removability (25). The skeletal system benefits include time and material savings. Moreover, bridge-shaped support structure was suggested rather than a tree-shaped one because it is stronger and more stable (26).

The second type of technique involves deforming the model after cutting it or printing it in blocks to lessen the need for support structures. Hu et al. proposed a model body based on the presumption of a specific printing orientation with minimal utilization of support materials due to the minor degree of deformation (27). Wang et al. introduced a method that simultaneously optimizes the printing direction and the associated cutting position after restricting the cutting direction to be perpendicular to the printing direction (28). The pyramid segmentation problem of the 3D model is proposed by Hu et al. without making any assumptions about the printing direction and cutting direction, and it is converted into a set accurate coverage problem for an approximative solution (27). To segment the provided 3D model, solve the pyramid segmentation problem. The pyramid shape is divided into the fewest possible pyramid shapes, and each pyramid shape is self-supporting in the correct positive direction; therefore, printing support is not necessary. The 3D model is roughly divided into pyramids, and each division block is further divided by its matching pyramid. The 3D model does not have to have a pyramid shape to be able to be printed, even if the pyramid shape does not require any support materials. The pyramid division of the model cannot ensure the minimum both the number of split blocks and the maximum material savings are optimal because, during the actual printing process, when the surface of the 3D model has only a slight inclination angle, it can be printed directly without the support materials.

Conclusion

The process of creating a model now takes much less time thanks to the advent of 3D printing, and since printing-related factors can be fully considered and processed throughout the design process, the created model will be more useful. Alternatively, for printing the research on further process optimization has accelerated the advancement of 3D printing technology. This paper summarizes the present studies from the two stages of model design and printing with regard to the job of optimizing model instantiation under the inspiration of 3D printing. The given digital 3D model was subjected to several analyses and processing steps in the model design stage based on the many functional specifications of the final instantiation model to ensure that it satisfied the specifications. But in actuality, the functional features that have been researched and the functional items that can be printed directly are only a small portion of the various things with various purposes that exist. Researchers can focus more on the investigation and study of the functionality of the model to help in the design of items that can be directly printed and have specific complex functionalities because 3D printing makes the manufacture of models much more convenient than geometry.

Researchers have adjusted each printing step during the physical printing stage in order to make the printing go smoothly, to further reduce printing time and resources, or to make the model's appearance have a certain effect after printing. Nonetheless, every assignment frequently favors one particular objective over other crucial aspects. For instance, dividing a model result in structural instability, whereas optimizing the support structure results in cost and time savings. It assumes that the model is printed in solid form rather than considering the model's physical structure. As a result, a thorough analysis of the potential optimization techniques for each printing step as well as a thorough model instantiation system in conjunction with the many functional qualities that the model should have been conducted.■

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