

ANALYSES AND SOLUTIONS ON TECHNICAL AND ECONOMICAL ASPECTS OF RAPID PROTOTYPING TECHNOLOGY

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Professional paper

This article deals with basic characteristics and problems in the area of technology of Rapid Prototyping using layered manufacturing technology. It belongs to progressive methods of model creation based on geometry obtained from CAD environment with application possibilities in different industrial spheres. Chapters are focused on optimization of Rapid Prototyping preparation process. There is also an algorithm that leads to the selection of suitable settings. Utilization of the algorithm is explained on a case of printing with the use of UPrint device and Catalyst software, a system created for the utilization of Fused Deposition Modelling technology. There are outputs in the form of graphs and tables accumulating information directly affecting economical aspects of printing. Conclusion brings ideas on possible further progress in this area that would include a solution for the generation of database with stored information about previous printing results.

Keywords: rapid prototyping, 3D print, algorithm, economical aspect

Analize i rješenja tehnologije brze izrade prototipa s tehničkog i ekonomskog gledišta

Stručni članak

Ovaj članak se bavi osnovnim karakteristikama i problemima u području tehnologije brze izrade prototipa, korištenjem 3D printanja. Ta tehnologija spada u progresivne metode stvaranja modela na temelju geometrije dobivene u CAD okruženju, s mogućnosti primjene u različitim područjima. Poglavlja su usmjerena na optimizaciju procesa 3D printanja. Tu je također algoritam koji prikazuje izbor optimalnih postavki. Upotreba algoritma je objašnjena na primjeru printanja s UPrint uređajem i Catalyst softverom, sustavom stvorenim za uprabu tehnologije modeliranja taložnim srašćivanjem. Postoje izlazi u obliku grafova i tablica s puno informacija koje izravno prikazuju ekonomsku isplativost printanja. Zaključak donosi ideje o mogućem daljnjem napretku u ovom području, koje će uključivati bazu podataka s pohranjenim informacijama o prethodnim rezultatima.

Ključne riječi: brza izrada prototipova, 3D printanje, algoritam, ekonomski aspekt

1 Introduction

Rapid Prototyping is the automatic construction of physical objects using technology. The first techniques for Rapid Prototyping became available in the late 1980s and were used to produce models and prototype parts. Today, they are used for a much wider range of applications and are even used to manufacture production-quality parts in relatively small numbers. The use of additive manufacturing for Rapid Prototyping takes virtual designs from computer aided design (CAD), transforms them into thin, virtual, horizontal cross-sections and then creates successive layers until the model is complete. The primary advantage of additive fabrication is its ability to create almost any shape or geometric feature [1].

2 Problems of Rapid Prototyping process

Rapid Prototyping method is one of the methods that use special computer format STL. From historical point of view it is the work of developers who established this format as output data form obtained after digitalization with 3D scanner. Polygon surfaces also known as facets represent the areas for volume description. The model in STL format created in some three dimensional CAD software has the surface constituted from a number of triangles. The number and size of triangles defines the preciseness of curvature of particular model surfaces. STL format can be used in two different forms: ASCII and binary form [4].

Currently there is a huge number of CAD software on the world market that allows constructors and designers to design the models according to their ideas that are used with addition of the third dimension. Nowadays all CAD software products provide functions and tools necessary

for export of created models in STL format that is further used in Rapid Prototyping process. The user of 3D technology can change spatial orientation according to his requirements. They should be based on the functionality and corresponding quality of complicated surfaces (complex surfaces, planar surfaces under angle, cavities, holes) and also on expected proportion of the used basic and support material with the focus on economical matters. In most cases automatic mode can be chosen for the definition of model position but in that case it is barely justified or explained on the basis of functionality of some part surfaces. The next parameter, important from the viewpoint of final quality and price, is the definition of thickness of a single printed layer. With this parameter is also related the style of model and support material addition as two basic building substances used for the prototype production. Material can be built as one unit or particular layers can be printed in grid with lower density, what reduces the printing price [11].

Factor of input data quality, factor of suitable software and physical part orientation and factor of relevant density and the building layers' style are the most problematic aspects in the process of the realization of Rapid Prototyping technology [3].

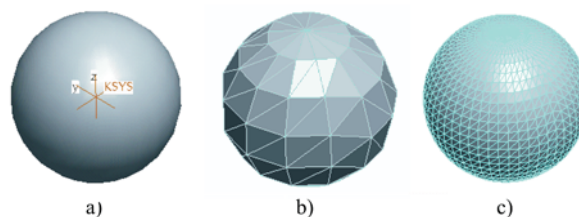


Figure 1 Example of STL format applied on sphere surface generated in Pro/Engineer. Size and number of triangles defines the preciseness of curvature of surfaces. a) 3D model, b) STL format with accuracy 0,5 mm, c) STL format with accuracy 0,05 mm.

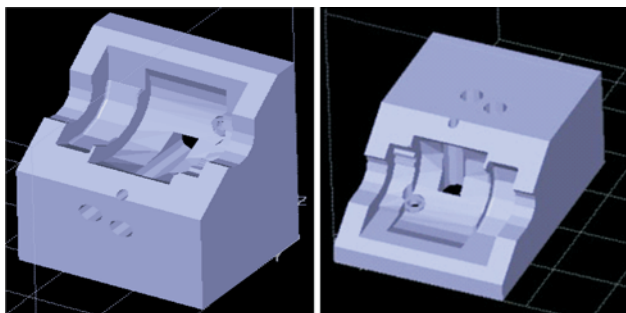


Figure 2 Model imported in Catalyst software for verification of economical impacts of different settings

3 Current situation and trends in the area of Rapid Prototyping

The method of Rapid Prototyping (RP) is most commonly used for rapid production of new part intended for presentation purposes. Manufactured models can also be used for different tests and analyses, for example for testing of fluids flow, aerodynamic tests, confirmation of results of FEM and DEM analyses. Another application area is covered with verification of assembling procedures and checking on their kinematical and dynamical properties. The sphere of RP application is moving even to departments that are not typically industrial like health care, archaeology, biorobotics. Typical examples are successfully created prototypes or reconstructions of bones, joints, missing elements of museum objects. In the frame of most modern approaches this method is starting to be used in situations with hard conditions for classic manufacturing technologies – space programs and detached external laboratories in hardly accessible regions. Created prototypes dramatically increase the level of possible engineering interaction, as real 3D objects are easier to explain and understand as presented 2D ideas of models. For testing purposes the models can be printed in scale, what can lead to lower requirements for testing forces, loads, etc. RP technology also shortens times for classical prototyping in the sense of creating – testing – redesigning – rebuilding and repeatability. There is a number of specific methods used in the area of RP: Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modelling (FDM), Solid Imaging (SI) or Multi-jet Modelling, 3D Printing (3DP) or Selective Binding, Laser engineering net shaping (LENS) [8, 12].

The last mentioned method is so far the most advanced process in terms of the range of mechanical properties of the generated metallic parts among all commercialised processes based on the layered manufacturing principle. It uses a high power laser focused onto a substrate to create a molten puddle on the substrate surface. Metal powder is injected into the melt pool to increase its volume. The powder ejection head moves according to the geometry of the first layer. After the first one new layers are built upon it until the entire object is reproduced. Involving of a substrate makes this process different from others.

These methods utilize specific hardware devices (printers) that use their own software based on the principle of reading and processing of input STL data. In spite of different manufacturers, such programs have the same characteristic features [2]:

- Settings for single layer resolution

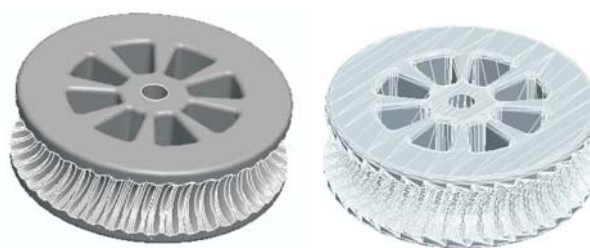


Figure 3 Example of model exported from graphical system Pro/Engineer to STL format

- Settings for density of model material
- Settings for density of support material
- STL processing to layer mode.

All these software solutions allow their user to change a large number of different settings. Changes are made by user himself. Programs for preparation of 3D print make many actions easier and more automatic, but deciding on the process about particular parameters is still up to the user. In the case of using the automatic mode these decisions are made by the program without explanation, so there is space for optimization of the setting contrary to user criteria. Solution could be found by implementation of deciding steps or by automatic decision with actual information about reasons running on background, eventually together with information about the parts already printed [10].

4 Selection of key parameters in the preparation process of Rapid Prototyping using FDM technology

For better orientation of user in the process of setting of suitable parameters during the preparation of printing an algorithm was elaborated which accumulated all factors and steps that lead to the selection of most suitable variant [9].

All the attempts were realized as a part of the preparation stage for printing on UPrint machine that utilizes FDM technology to build the prototype. This technology, developed by Stratasys, uses the software program to orient the model and generate building slices. Printer dispenses with basic building material and support material which is used if necessary for the creation of holes, cavities, drafts, etc. Each material has its own nozzle. Creation of particular prototype layers using FDM method is shown in Fig. 4.

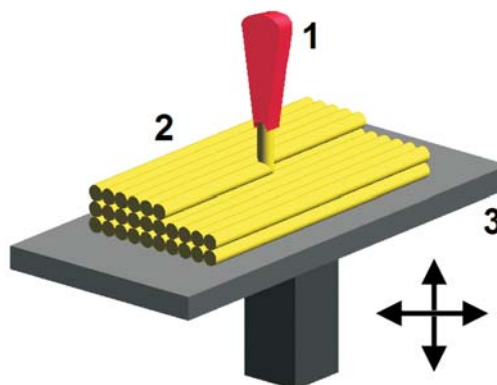


Figure 4 Schematic model of Fused Deposition Modelling technology (1 - nozzle, 2 - building material, 3 - movable table) [16]

First step is to define the surfaces and constructional points that represent functional features of part and thus

they should condition requirements on quality. Considering these surfaces it is necessary to think about the number and type of existing reference entities in the model that can be used for part orientation. In case that STL data do not have the required quality there is a need to increase the number of polygons and re-export to STL format (STL editing). After importing of STL file we get to the part orientation. Commonly there is an automatic option solved by several software procedures. These steps can be contrary to the user's requirements.

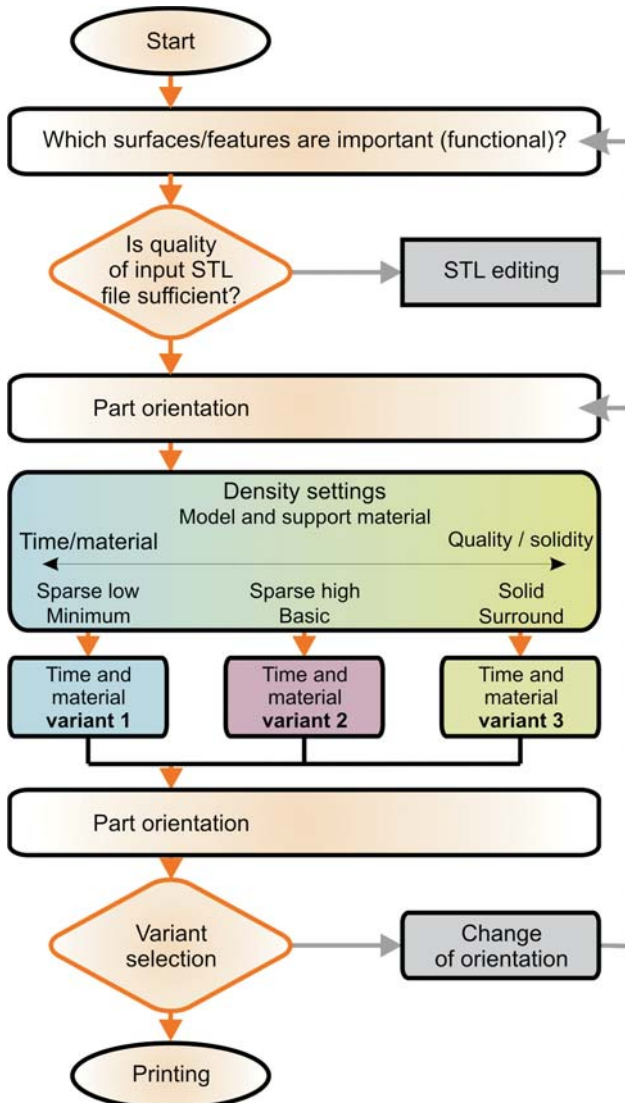


Figure. 5 Algorithm created for RP preparation process

A more effective way would often be manual orientation, where the position of part is defined by the relation of its surface or edge to the working board or to some coordinate axis of the used environment. Available are also standard functions like rotation and scaling. With the part oriented we can proceed to another settings that include style and density of particular printing layers. The value of minimal thickness of a single layer is conditioned by hardware properties of printer or building material. There is a parameter usually called Model interior, for the quality of basic building material setting. Among standard options there is Solid mode, advised by manufacturer, as the printed material results in one whole. Other possibilities are Sparse-Low density and Sparse-high density. They save basic material by creating the grid of cavities inside the volume.

Last mentioned options are applied mainly in huge models without requirement on technical functionality. Walls are partially weakened and have lower strength. Support fill is another parameter that is very similar to the previous one except that it defines the usage of support material. It is often applied for skew surfaces and holes. Common options are Minimum, Basic, Sparse and Surround. For construction reasons it is wise to use Sparse variant to avoid the wall crash because of its small thickness. Surround option on the other hand is used for complicated models. Support material then covers all the model and needs to be removed in special washing device. Lower settings for density and volume of used basic and support material answer to lower strength and functional properties but at the same time present assumption for lowering the cost of prototype creation. Models created by using low parameters are sufficient for most common application purposes – for presentations. Higher parameters of quality mean longer printing times and higher energy consumption, but the utilization possibility of such models is much higher as they can be used instead of real functional parts. The next step in RP preparation process is to define the location of the model on the working board of the printer. The goal is to optimally place the printed model considering the possibility of allocation of other prototypes (printed together or later) on the same printing board. After thinking of all mentioned parameters the user is supposed to make a decision that should be based on information about printing economy, volumes of both kinds of material and relevant printing times. A good start for making a right decision is to have all information accumulated at one place and thus to have much better idea of expected printing results. In case of interest there is a way to get back to the part orientation step [14].

5 Economic aspects of Rapid Prototyping

The following example of the preparation of FDM printing process describes the problems solved by the previously mentioned algorithm. The model created in Pro/Engineer was exported in STL format and imported into Catalyst software. First the model was oriented as it can be seen in Fig. 2 left, while setting the quality of building material to value Solid and consequently to Sparse-high density and Sparse-Low density. After keeping the parameter of support material on Basic level we obtained data written in Tab. 1.

Table 1 Output values of material usage and printing time for the first model orientation

Model 1	Solid	Sparse high	Sparse low
Model/ cm ³	231,23	176,75	96,53
Support/ cm ³	10,05	10,04	10,05
Time/ h	7:22	7:12	5:07

In another situation the 3D model was applied to the working board with different orientation. In this case the material parameter was also changed from Solid to Sparse-high density and Sparse-low density. The obtained results are shown in Tab. 2.

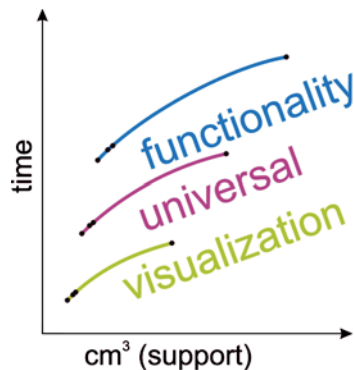
The setting for support material was changed as well in the following order: Minimum, Basic, Sparse and Surround. Information on relevant outputs can be found in Tab. 3.

Table 2 Output values of material usage and printing time for second model orientation

Model 2	Solid	Sparse high	Sparse low
Model/ cm ³	231,01	177,15	98,2
Support/ cm ³	11,9	11,9	11,9
Time/ h	8:13	8:15	6:05

Table 3 Output values of material usage and printing time for third model orientation

Model 3	Min.	Basic	Sparse	Surround
Model/ cm ³	177,13	177,15	177,14	177,19
Support/ cm ³	10,36	11,9	12,64	39,06
Time/ h	7:59	8:15	8:21	10:37

**Figure 6** Dependencies of printing time on used material

The presented Fig. 6 is a graphical expression of the changes in support material application style based on values from previous tables. Curves describe dependence of printing time on usage level of support material. Areas expressing the character of printing from the viewpoint of its economy are situated between these curves. User can decide on concrete category according to the expected or requested application field of printed part [6, 13, 15].

6 Conclusion

The technology of Rapid Prototyping with the use of FDM technology belongs to progressive methods of model creation based on geometry obtained from CAD environment. It is used in different industrial spheres thanks to high flexibility and rapid prototype generation. This article is focused on the optimization of RP preparation process. It describes the algorithm that leads to the selection of suitable settings. Utilization of such an algorithm is explained on a case of printing with the use of UPrint device and Catalyst software. Graphs and tables show output values obtained from the printing software. Assets for the future could lie in the possibility of having all the necessary information at once and thus of making the right decision on proper settings variant based on real facts. The realization of such innovation can be achieved through the generation of a database that would process and archive all output data after printing the part models. Relations should be observed between the chosen parameters of basic and support material, times of printing and quality, all including economical aspects. This supportive database system would, together with the software philosophy based on described algorithm for the selection of suitable parameters, assure maximal economy while providing comfort and effective way of selection.

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