Analyze and optimization parametrs for protatiping using 3D printer

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Abstract. As part of this work, a simulation model was constructed to evaluate the print quality of three-dimensional objects using a 3D printer. A study was conducted using non-contact scanning of a 3D model and varying the parameters affecting print quality, followed by an assessment of the degree to which the printed 3D model corresponded to its standard using software. The result of this study is the obtained values of the optimal printing parameters of the 3D model, which allow to obtain a high estimate of the degree of correspondence of the printed 3D model to its standard, and, consequently, high quality printing on a 3D printer.

Keywords: simulation model, 3D printer, optimal print settings, analyze

1. Introduction
3D printing (also known as additive manufacturing) is the process of creating solid three-dimensional objects of any shape from a digital computer model. 3D printing is achieved through the so-called additive processes, during which each layer of the material is placed in a different form. This distinguishes it from traditional machining techniques, most of which are based on the removal of material by cutting or drilling (subtractive processes). Additively produced objects can be used at any stage of the product life cycle, from the creation of preliminary samples (for example, in rapid prototyping) to full-fledged production (for example, in fast production), in addition to machining and post-production refinement. The relevance of the work is due to the requirements of design bureaus, universities, departments for the manufacture of prototypes of the developed 3D models, as well as to accelerate the process of commissioning [1].

2. Simulation model
To find the optimal printing parameters for the 3D model in order to improve product quality and develop a methodology for assessing the print quality of three-dimensional models, a simulation model was constructed [2], shown in Figure 1.
The principle of operation of this simulation model is that having an electronic 3D model of the product as a reference, the prototype of which is printed using a 3D printer, is subsequently scanned on a 3D scanner. Next, an assessment is made of the degree of correspondence between the obtained cloud of prototype points and the standard, for further adjustment of the prototype print parameters.

To assess the degree of compliance, a software product was used based on the method of assessing the degree of similarity of three-dimensional objects, as well as methods of formal analysis and analysis using an artificial neural network apparatus, it relies on the voxel form of representing three-dimensional objects, but in contrast to them, geometric comparison method.

The general principle of this method is simple and consists in bringing the reference object to the form of a voxel array, so that the resulting voxel array includes only those voxels within which any part of the original 3D model is located, i.e. an array of voxels will be obtained, combined in such a way that with some accuracy determined by the size, and, consequently, the number of voxels of the resulting array, repeat the shape of the original reference object [3].

The compared object is presented in the form of a point cloud, generally ambiguous, containing defects and noises, and repeats the shape of the scanned real object. Those, after performing clipping of interference in the point cloud, scaling and matching in the space of the compared objects, a significant part of the cloud points will be within the voxels of the array corresponding to the reference object, from which we can conclude that the part of the reference model represented by such voxels is present in the point cloud, and therefore in a real object.

This method includes two steps:

- the preparatory stage, at which the formation of a voxel array is carried out according to the initial reference three-dimensional model, cutting off interference in the initial cloud of points, scaling and overlaying the compared objects;
- stage of analysis, which analyzes the presence of cloud points within the voxels of the array, counts the "existing" voxels and determines the ratio of the number of "existing" voxels to their total number of voxels in the array, which is a measure of the compliance of the compared objects.

Moreover, this method of comparing three-dimensional objects and the proposed measure of their similarity have such advantages as: ease of interpretation of the results, such as measures of the presence of the standard in the scan results of a real object, ease of visualization of the application results [4], and to some extent resistance to interference in a point cloud, because under conditions of relatively correct overlapping of the compared objects on top of each other, possible noise points...
outside the array voxels will not be taken into account, while within the voxel size it is still possible to take into account the non-noise point of the cloud, under conditions of some possible random deviation of its coordinates [5].

3. Research

To obtain optimal printing parameters for a three-dimensional model, an algorithm was developed, which is shown in Figure 2, and a number of experiments were carried out. These experiments included the printing of a three-dimensional model [6] with ABS plastic - a calibration cube with different printer settings and three-dimensional model printing parameters specified in the slicer program and further scanning of the printed three-dimensional models to obtain an assessment of the degree of conformity with the standard [7-9].

![Figure 2. The algorithm for finding optimal print settings](image)

The results of the experiments presented in Tables 1-4 show the optimal printing parameters of the model for both a 3D printer and for preparing for printing in a slicer program. In the first experiment, the results of which are presented in table 4, we change the temperature of the extruder, but leave the following fixed parameters:

- print speed - 60 mm / s.;
- number of microsteps per 1 mm - 80 microsteps;
- nozzle diameter - 0.4 mm.

| t,°C | 220 | 225 | 230 | 235 | 240 | 245 | 250 |
|------|-----|-----|-----|-----|-----|-----|-----|
| №1  | 91% | 91% | 90% | 93% | 97% | 99% | 96% |
| 2    | 91% | 92% | 91% | 95% | 95% | 96% | 98% |
| 3    | 90% | 90% | 90% | 91% | 99% | 98% | 95% |
| 4    | 93% | 91% | 93% | 92% | 99% | 99% | 95% |

The results were reflected in the graph presented in Figure 3.
Figure 3. Comparison of the degree of conformity of the prototype to the standard when the temperature of the extruder

The graph shows that the highest assessment of the degree of conformity of the three-dimensional model to the standard is observed at a print temperature of 245 °C, which makes it as applicable as possible to print, to achieve the best result [10].

In the second experiment, the results of which are presented in table 5, we change the diameter of the nozzle, but leave the following fixed parameters:

- print speed - 60 mm/s;
- number of microsteps per 1 mm - 80 microsteps;
- extruder temperature - 245 °C.

Table 2. Comparison of the degree of correspondence of the 3D model to the standard with temperature

| № | D, mm | 0.3 | 0.4 | 0.5 | 0.6 |
|---|-------|-----|-----|-----|-----|
| 1 | 99%   | 98% | 98% | 97% |
| 2 | 99%   | 99% | 98% | 98% |
| 3 | 98%   | 98% | 98% | 96% |
| 4 | 99%   | 97% | 97% | 97% |

The result of this experiment, as can be seen in the graph shown in Figure 4, is that a nozzle with a diameter of 0.4 mm is most suitable for printing.

It should be noted that the nozzle diameters considered are used when printing with a plastic rod with a diameter of 1.75 mm. When using a plastic rod for printing with a diameter of 3 mm, the value of the optimal nozzle diameter may differ [11-12].
Figure 4. Comparison of the degree of conformity of the prototype to the standard when changing the diameter of the nozzle

The result of this experiment, as can be seen in the graph, is that a nozzle with a diameter of 0.4 mm is most suitable for printing.

In the third experiment, the print speed is checked, namely, at which we get the best quality. The results of this experiment are presented in table 3 and figure 5. Fixed parameters: nozzle temperature, nozzle diameter and number of microsteps.

Table 3. Comparison of the degree of correspondence of the 3D model to the standard when changing print speed

| V, mm/s | 40  | 50  | 60  | 70  | 80  |
|---------|-----|-----|-----|-----|-----|
| №1      | 99% | 99% | 99% | 97% | 96% |
| №2      | 98% | 99% | 98% | 99% | 98% |
| №3      | 99% | 99% | 99% | 98% | 95% |
| №4      | 99% | 98% | 99% | 98% | 95% |

Figure 5. Comparison of the degree of conformity of the prototype to the standard when changing print speed
The last experiment was to check the effect of the number of microsteps on 1 mm of extruder movement. Remained unchanged - temperature, print speed, nozzle diameter. The results of this experiment are presented in table 4 and in figure 6.

**Table 4.** Comparison of the degree of correspondence of the 3D model to the standard when changing the number of microsteps

| N-steps | 60 | 70 | 80 | 90 | 100 |
|---------|----|----|----|----|-----|
| 1       | 98%| 98%| 99%| 97%| 96% |
| 2       | 95%| 97%| 99%| 99%| 95% |
| 3       | 96%| 99%| 98%| 98%| 97% |
| 4       | 98%| 99%| 99%| 98%| 97% |

**Figure 6.** Graph of the degree of correspondence of the 3D model to the standard when changing the number of microsteps per 1 mm of movement of the print head

From the results of the experiment, presented in Table 4, it can be seen that an increase or decrease in the number of microsteps leads to a deterioration in quality, with a large number of layers the layers are poorly soldered, and when they are reduced, on the contrary [13], the previous layer does not have time to cool down and plastic overflows.

4. Conclusion

These experiments showed that when the rod used is 1.75 mm thick and the deposition layer thickness is 0.2 mm, the best printing parameters for a 3 D model are as follows:

- print speed - 60 mm / s.;
- number of microsteps per 1 mm - 80 microsteps;
- extruder temperature - 245 ° C;
- nozzle diameter - 0.4 mm.

The main disadvantage of the described method is the presence of a lot of “noise” in the point cloud, the scanned model, which complicates the subsequent work with it. There is a need for additional filtering of "noise" and the removal of unnecessary points of the background space on which the scan took place. This disadvantage is eliminated with the help of additional application software.
5. References

[1] Chang’an Hu and Wenbo Du 2018 *Materials Science and Engineering* vol. 394 pp 032063-1 – 032063-2.

[2] Mahamani A, Kumar P, Ismail K, Jawahar S, T Chiranjeevi Reddy, TVijayasai, T Venkata Phaneendra, V Uday sankar and V Gopi chandu 2018 *Materials Science and Engineering* vol. 390 pp 012100-3 – 012100-5.

[3] Varnavsky A N 2018 *Journal of Physics: Conf. Series.* vol. 1210 pp 012156-4 – 012156-5.

[4] Khan S F, Zukhi M M, Zakaria H and Saad M A M 2019 *Materials Science and Engineering* vol. 670 pp 012048-1 – 012048-2.

[5] Wang Y, Liu Y S and Meng J S 2019 *Materials Science and Engineering* vol. 479 p 012088-4.

[6] Vanek J, Galicia J A G, Benes B, Mech R, Carr N, Stava O and Miller G S 2014 *Packmerger: a 3D print volume optimizer* (Great Britain: John Wiley & Sons, Incorporated) pp 322-332.

[7] Kyratsis P and Tzetis D 2018 *Materials Science and Engineering* vol. 416 p 012086-1.

[8] Khan S F, Zakaria H, Chong Y L, Saad M A M and Basaruddin K *Materials Science and Engineering* vol. 429 pp 012101-1 – 012101-2.

[9] Yiran Yuan 2020 *Materials Science and Engineering* vol. 711 pp 012014-1 – 012014-3.

[10] Cwikla G, Grabowik C, Kalinowski K, Paprocka I and Ociepka P 2017 *Materials Science and Engineering* vol. 227 pp 012033-1 – 012033-2.

[11] Hongyuan Zhao, Xiaodong Liu, Wei Zhao, Gong Wang and Bingshan Liu 2019 *Journal of Physics: Conf. Series.* vol. 1213 pp 052037-4 – 052037-6.

[12] Sljivic M, Pavlovic A, Kraisnik M and Ilic J 2019 *Materials Science and Engineering* vol. 659 pp 012082-4 – 012082-7.

[13] Chua C K and Leong K F 2017 *3D printing and additive manufacturing: principles and applications: the 5th edition of rapid prototyping: principles and applications* (New Jersey: World Scientific Publishing Co.) p 345.