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POEAM – A Method for the Part Orientation Evaluation for Additive Manufacturing

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Abstract

In the industrial application of additive manufacturing processes, a significant amount of time and resources are dedicated to the orientation and pre-print setup of the geometry. Steps such as the generation of support structures and the process simulation are among the most time-consuming. For the thorough assessment of an orientation of a given geometry, even more criteria, like print time or surface quality, need to be considered. POEAM proposes a method for an efficient assessment of a set of orientations, by means of well formulated criteria and an early elimination of insufficient orientations. The goal is to narrow the search field, so costly preparation steps will only be performed on orientations that promise a superior end result. Furthermore, POEAM is an automated process, which means it can be performed with minimal human interaction, resulting in an optimum regarding cost-efficiency and evaluation time. The method was applied to a representative geometry and has shown results that confirm the above-mentioned advantages.

Keywords: 3D-Print; Additive Manufacturing; Part Orientation; Pre-print; Simulation; AM; SLM.

1. Introduction

During the Additive Manufacturing (AM) process - especially during the SLM (Selective Laser Melting) process - extensive user experience is required, particularly in preprocessing. As AM becomes more widespread, however, users with a lower level of experience are being addressed in increasing numbers. The lack of detailed process knowledge and experience on the part of the user often leads to incorrect alignment of the components in the machine's building chamber and to incorrectly arranged support structures in the event of overhangs. As a result, AM components cannot be built up to the aspired geometrical precision in the first build process, or the process cannot even be successfully completed. This leads to delays in the process and additional costs when using AM technology.

The aim of the described method is to automate the pre-print preparation of a CAD design so that minimal human interaction is required. This will free the engineer of tedious tasks that can be performed by a machine faster and more efficiently.

2. State of the Art

In addition to a pure fitting of the geometry into the machining area of an AM system, the alignment of the component plays a major role due to the layered structure. This applies both to a successful build process and to the

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later strength values of the component. Many of the methods used up to now for aligning the geometry are mainly based on the optimization of the alignment with regard to geometric parameters. While these rules for the setup of the geometry can be represented relatively well (e.g. "smallest possible projected area", "supports from an inclination of the surface of $>45^\circ$ " or "no large horizontal surfaces if possible") [1], the relationship between the alignment of the component and the later component properties is much more complex [2]. Some work was done in the past years to determine optimized build orientations regarding various target values for AM processes [3-6]. However, it is still only rudimentarily possible today to map both technical production requirements and strength-relevant requirements during component alignment at the same time.

Parallel to the production of AM components, the simulation of the construction process has been further advanced in recent years [7, 8]. Today, it is therefore possible to carry out a production simulation before the start of the build process using various software tools. Since only an optimal building process produces an optimal component, these simulations are now part of the industrial standard [9]. Unfortunately, the AM simulation of the build process takes a very long time. This means that a simulation cannot be carried out for every alignment in the building space.

3. POEAM – The New Approach

The "POEAM" (Part Orientation Evaluation for Additive Manufacturing) approach presented here offers the possibility of significantly reducing the number of necessary simulations. The algorithm provides a pre-selection of component orientations for the user, based on different user inputs. The necessary simulations are thus reduced to a few or only one run. Due to the complexity of an AM simulation, no self-implemented algorithms such as [10] are used for these runs, but rather commercially available simulation tools. In this example, the "Amphyon" software from AdditiveWorks [11] was used, other software tools are also possible.

POEAM was developed with the manufacturing process of SLM in mind, but the method is not limited to that. With only small adaptations, it can be used for various forms of AM. In order to take advantage of the proposed method, four user inputs need to be given:

- The geometry of the part;
- A search field of orientations;
- A set of criteria to evaluate the part on;
- The properties of the printer.

The first point defines the geometric shape of the component. The second point determines the angle of rotation within which the alignment of the component is to be varied in three axes. The third point defines criteria according to which the orientations found are evaluated. The fourth point specifies the AM machine's properties for the process simulation. As a result, the POEAM method yields the optimal orientation of the produced part in the building chamber of the AM machine, considering the specified parameters.

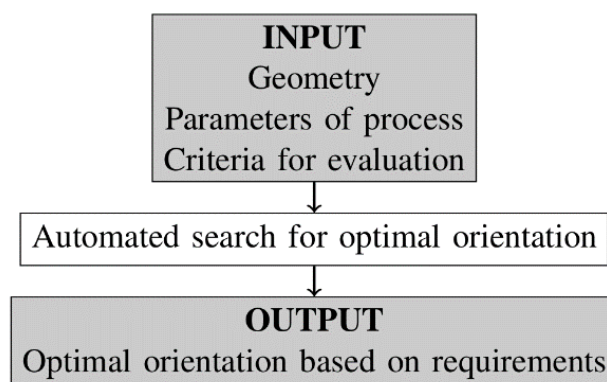


Figure 1. Workflow Overview

4. Search Field Definition

The user-defined search field specifies the range within which the geometry can be rotated to find the optimal orientation. This includes upper/lower angles and rotation increments for the specified rotation axis. Before the actual evaluation of the criteria, this search field can be narrowed by identifying symmetries and equivalent orientations.

4.1. Symmetries

If two orientations show mirror symmetry in a plane perpendicular to the baseplate, only one of the two symmetrical orientations need to be evaluated. From the AM point-of-view, these two orientations are identical, because a rotation of the part around the z-axis is of no consequence to the printing process.



Figure 2. Two orientations showing symmetry

4.2. Equivalent Orientations

Two orientations may be equivalent, as in the case of symmetry (see 2.1). Another cause for equivalence can be the rotation process itself. Depending on the used method to rotate the initial geometry, two sets of rotations (e.g. around the global x- and y-axes) may result in an identical orientation of the part. This needs to be detected and equivalent orientations need to be excluded from the analysis.

5. Criteria Definition

The results generated by variation are evaluated on the basis of a list of criteria. To check the fulfillment of a single criterion, a numerical boundary is required. For each criterion a threshold value range is defined within which a result value is permissible. The fulfillment of a criterion is expressed as a percentage within the defined range. All values below this range are regarded as insufficient (0%) and will be excluded from further analysis. Values above the defined range are accepted as sufficient (100%). Values within the boundaries are scored in relation to their distance from the boundary's edges, with values between 0 and 100%.

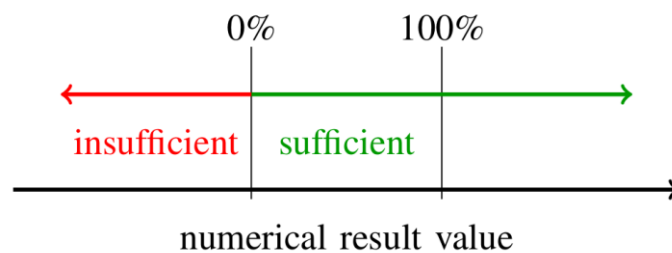


Figure 3. The scoring scheme

This scoring scheme allows for the easy recognition of insufficient orientations (score of 0%) and the rating of sufficient orientations by means of their relative fulfillment.

5.1. List of Criteria

The user needs to define a list of criteria, upon which the orientations can be evaluated. To illustrate the process, the following exemplary criteria are defined:

- The interface area between part and support structure;
- The height of the oriented part;
- The time required to build the component in this orientation.

The list is by no means exhaustive and needs to be extended for a productive application.

5.2. Weighted Total Score

For each criterion, the orientation is given a partial score between 0 and 100%. Those partial scores are summed up into one numerical value. The partial scores are weighted by the user, giving certain criteria priority over others. This “Weighted Total Score” is used to determine the orientations that have the highest overall fulfillment of the required characteristics. Visualizing the orientations with a high weighted total score in a heat map shows the formation of clusters.

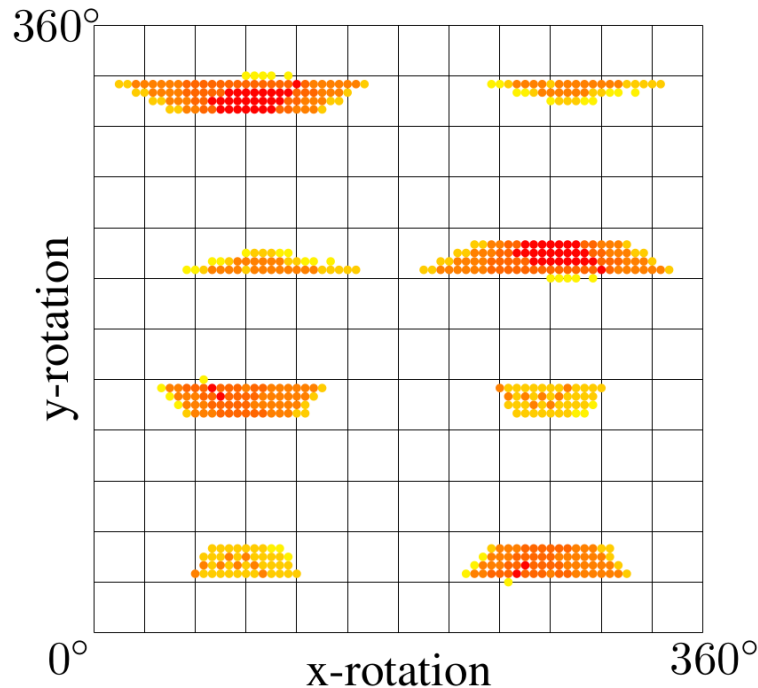


Figure 4. Heat map of weighted total scores

This indicates regions of orientations with a high criteria fulfillment. Inside those regions a refined search may be advantageous. This is very useful if the results are not yet accurate enough or if the search is carried out in several steps with increasing accuracy.

6. Criteria Checking Order

A critical step in the procedure is the checking order of the criteria, since the goal is the early exclusion of insufficient orientations. This means, if an orientation cannot fulfill a criterion it will be excluded from further analysis. This non-fulfillment needs to be detected early in the analysis, so no resources are wasted on an orientation that will eventually fail to satisfy the requirements. To achieve this, two approaches will be illustrated.

6.1. Sort by Runtime

The criteria may be sorted by the individual run time needed to calculate and check a criterion. This results in criteria that are quick to calculate being checked first, whereas time-consuming criteria are checked last.

6.2. Sort by Previous Exclusion

In contrast to the static order of criteria being sorted by runtime, sorting by previous exclusion changes the order dynamically during the analysis. If an orientation is excluded due to non-fulfillment of a criterion, that criterion will be the one checked first on the next orientation. This assumes, that orientations that are similarly oriented will yield similar results and are there for likely to (not) fulfill criteria to a similar degree.

Both approaches rank criteria that may lead to an exclusion higher, than obligatory criteria that are of interest, but cannot lead to an exclusion. Such an obligatory criterion may be the volume of the support structure, which the user wants to consider in the weighted total score, but should not result in an exclusion.

Certain criteria are dependent on the results of another criterion, e.g. for the calculation of the time to print the orientation, the build height has to be calculated first. Dependencies like this have to be considered during the generation of the checking order, so the necessary input values for a criterion are available upon calculation.

7. The Procedure

The workflow starts with the user defining

- The geometry;
- The search field;
- The criteria including their boundaries and weights, and
- The printer parameters.

Knowing the geometry of the part, equivalent orientations can be discarded. By evaluating the criteria that were set, the criteria are sorted by runtime. After setting the criteria checking order, the analysis is started. During the analysis the checking order is changed dynamically, depending on previous exclusions.

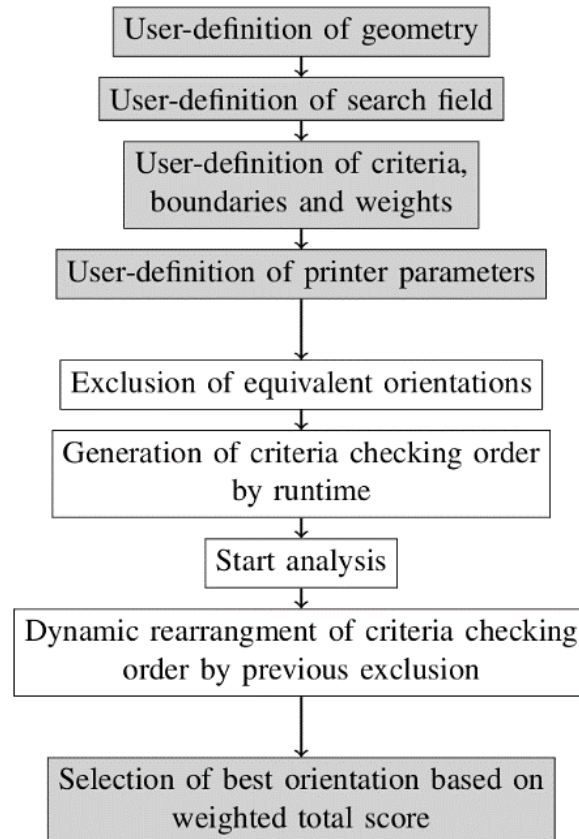


Figure 5. The workflow

The last step of the analysis is the selection of the best orientation, based on the highest weighted total score.

8. Demo

The following section is an exemplary orientation, using the method described above. The orientation was performed by a prototype, which implements key features, but has not yet all the functionalities described in the previous sections. The program shows nevertheless, the efficiency of the process and its potential to improve the current print preparation.

To include the critical steps of support structure generation and process simulation, the tool “Amphyon” (Amphyon Trial Version; Source: Additive Works GmbH Germany [Additive]) was used.

8.1. Input and Criteria Definition

The first step consists of the user providing the CAD geometry of the part. The geometry in this demo had the following characteristics:

- Points: 33,854;
- Edges: 101,598;

- Faces: 67,732.

The relevant criteria for the analysis were:

- Evaluate all possible orientations in 3D space, with a rotation increment of 10°. Refine the search around promising orientations to an increment of 5°;
- The critical overhang for part surfaces is 35°;
- No support on running surface, located at center of the geometry;
- Low print time;
- Small support interface (area on the part which needs support);
- Low stresses and distortions in the final part;
- Material: Steel 1.4404.

For the simulation parameters the properties of a “Concept Laser M2” laser cusing machine were set.

8.2. Results

As shown in figure 3, a score of 0% is considered insufficient and results in the exclusion of the orientation. Figure 4 shows the results of the refined search, where dark red indicates a high criteria fulfillment. The graph shows the formation of clusters around promising orientations. An interesting feature is the half-oval form of the clusters (e.g. at a y-rotation of 150°), which result from the exclusion process. This shows that an exclusion of insufficient orientations can save calculation time, but also makes the analysis less intuitive and requires some kind of automation.

After the first sweep, before the support generation and the process simulation, the first exclusion was conducted. The exclusion rate was at 92%, which means only 8% of the orientations analyzed met the criteria. Only those remaining orientations were considered in the following support generation and process simulation.

Assuming that each cluster centers around a local maximum, one orientation from each cluster was run through the support generation and process simulation, resulting in 8 orientations checked. After this step only 3 orientations (0.2%) remained, which fulfilled all the criteria. From this list the best candidate was chosen by finding the one with the highest total weighted score.

The value of an estimate for the time saved by automating the process is limited, since such a process would not be performed manually in an industrial application. Therefore, the time savings will be illustrated indirectly, with the following result values:

- 92% of all orientations could be excluded after the first sweep and before the support generation and process simulation;
- Less than 1% of all orientations fulfilled all the requirements.

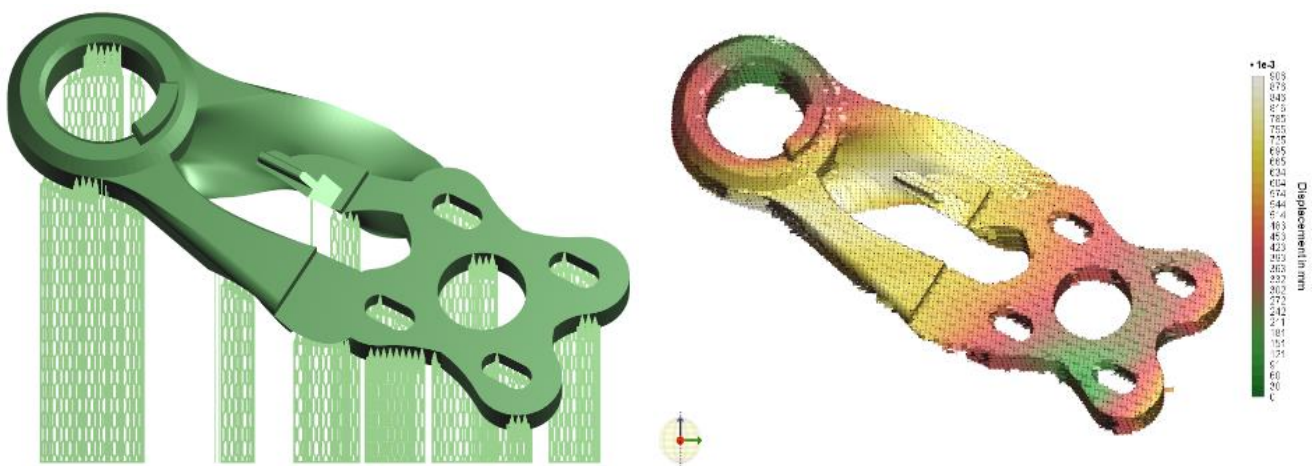


Figure 6. Exemplary results of process simulation in Amphyon

In order to give some estimate of the analysis duration, the following list shows the computing time of the demo on a “HP Elite Book 8740w”:

Table 1. Computing time

Time for orientation and checks:	3 min
Time for support generation and simulation (using Amphyon):	~ 24 h
Total time:	~ 24 h

Comparing the time needed for the orientation and checking of the criteria, to the total time needed for the whole analysis, it stands out that this step has only a marginal impact on the analysis time. The main portion of the computational resources is consumed by the support generation and the process simulation. This fact emphasizes the importance of limiting the number of orientations on which these costly operations are performed.

9. Conclusion

The potential of the proposed method lies in the simplification of the print preparation process. As the exemplary demo has shown, POEAM enables the unexperienced user of AM technology to prepare a geometry to be manufactured accurately and in compliance with required properties. In addition, POEAM also offers the benefit of saving time during the print preparation, by automating the process and therefore making the use of AM more efficient. This makes the method also attractive for expert users, who want to maximize the quality of their work.

10. Acknowledgement

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11. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

12. References

- [1] Leutenecker-Twelsiek, B., Klahn, C., & Meboldt, M. (2016). Considering Part Orientation in Design for Additive Manufacturing. *Procedia CIRP*, 50, 408–413. doi:10.1016/j.procir.2016.05.016.
- [2] Pant, P., Proper, S., Luzin, V., Sjöström, S., Simonsson, K., Moverare, J, S. Hosseini, V. Pacheco, Peng, R. L. (2020). Mapping of residual stresses in as-built Inconel 718 fabricated by laser powder bed fusion: A neutron diffraction study of build orientation influence on residual stresses. *Additive Manufacturing*, 36, 101501. doi:10.1016/j.addma.2020.101501.
- [3] Das, P., Chandran, R., Samant, R., & Anand, S. (2015). Optimum Part Build Orientation in Additive Manufacturing for Minimizing Part Errors and Support Structures. *Procedia Manufacturing*, 1, 343–354. doi:10.1016/j.promfg.2015.09.041.
- [4] Delfs, P., Tjows, M., & Schmid, H.-J. (2016). Optimized build orientation of additive manufactured parts for improved surface quality and build time. *Additive Manufacturing*, 12, 314–320. doi:10.1016/j.addma.2016.06.003.
- [5] Matos, M. A., Rocha, A. M. A. C., & Pereira, A. I. (2020). Improving additive manufacturing performance by build orientation optimization. *The International Journal of Advanced Manufacturing Technology*, 107(5-6), 1993–2005. doi:10.1007/s00170-020-04942-6.
- [6] Moroni, G., Syam, W. P., & Petrò, S. (2015). Functionality-based Part Orientation for Additive Manufacturing. *Procedia CIRP*, 36, 217–222. doi:10.1016/j.procir.2015.01.015.
- [7] Cook, P. S., & Murphy, A. B. (2020). Simulation of melt pool behaviour during additive manufacturing: Underlying physics and progress. *Additive Manufacturing*, 31, 100909. doi:10.1016/j.addma.2019.100909.
- [8] Lindgren, L.-E., Lundbäck, A., Fisk, M., Pederson, R., & Andersson, J. (2016). Simulation of additive manufacturing using coupled constitutive and microstructure models. *Additive Manufacturing*, 12, 144–158. doi:10.1016/j.addma.2016.05.005.
- [9] Song, X., Feih, S., Zhai, W., Sun, C.-N., Li, F., Maiti, R., J. Wei, Y. Yang, V. Oancea, L. R. Brandt, Korsunsky, A. M. (2020). Advances in additive manufacturing process simulation: Residual stresses and distortion predictions in complex metallic components. *Materials & Design*, 193, 108779. doi:10.1016/j.matdes.2020.108779.
- [10] Rodgers, T. M., Madison, J. D., & Tikare, V. (2017). Simulation of metal additive manufacturing microstructures using kinetic Monte Carlo. *Computational Materials Science*, 135, 78–89. doi:10.1016/j.commatsci.2017.03.053.
- [11] Additive Works GmbH, (2020). Simulation- based process preparation software for Laser Beam Melting, Available online: <https://additive.works/> (accessed on December 2019).