Infill Pattern and Density Optimization for 3D Printing with Analytical Physics

A novel approach to provide fused deposition modeling printers software to create stronger, lighter and faster to print parts

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1.1: Importance of 3D Printing

Three dimensional printing is considered additive manufacturing because it does not remove material to create a final product. Instead, it adds materials to create the final product. A non-example of this would be removing material from a block of metal until it looks like a sponge. This wastes the material that is removed from the block. However, additive manufacturing would save that material because it creates parts without wasting material.

3D printing is also is very precise, therefore, it can be used for very small but ornate and complex parts. This is especially useful for rocket parts. Every kilogram in a rocket costs about $18,500 to lift, and every gram reduction can save money.

3D printing also breaks the barrier of manufacturing between small startups and large corporations. It greatly reduces the sunk costs of manufacturing a new product.

1.2: Current Software and Capabilities

Current 3D slicing softwares, such as Cura and Slic3r have only certain capabilities when it comes to multi-infill density/pattern prints. With the example of Cura, the software only allows the user to change the infill density and pattern by themselves, however, there is no automation of the system.

Researchers at the School of Mechanical Engineering in the Southeast University, China, have developed similar algorithm that bases the changes of infill density on the area of the layer. The algorithm they created does not account for any simulation data.

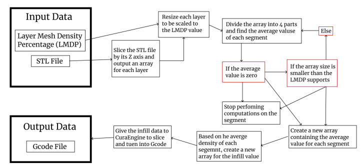
2: Engineering Goal

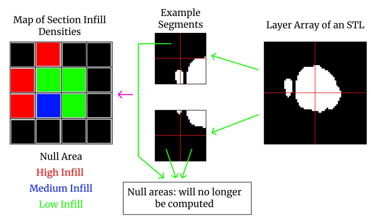
The goal of the project is to create an algorithm that will determine variable density and generate the pattern of infill in a 3D printed part in order to maximize the force withstood by the object and minimize the mass of the object. We will write the program in Python, test our program with FreeCAD and other simulation libraries, and 3D print our parts on the Creality CR 10 printer using PLA, ABS, and PCTPE filaments.

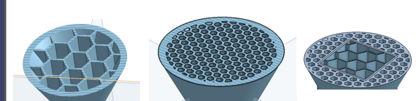
3.1: Algorithm Design

This algorithm uses the relative area of a section of a slice in order to determine the infill of that area.

Pros	Cons
Computationally lighter compared to other algorithms	The algorithm does not account for split parts if the LMDP is too high
Faster print times	Does not use simulation data to make design choices
The prints are achievable by an FDM printer	



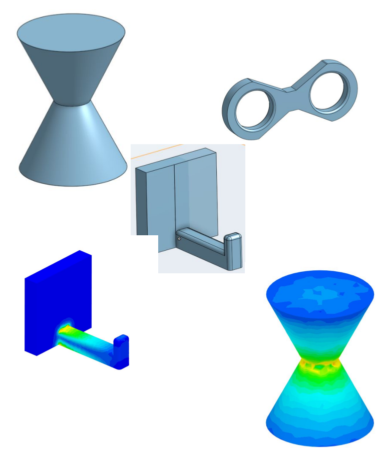




3.2: Data

To gather data, we simulated 4 different types of objects and saw the maximum force they could hold. For the torque and tension data, they were done multiple times to simulate stress at different points of the objects.

Top-Down Compression	20% Infill	60% Infill	100% Infill	Area Based Variable Infill
Trial 1 (N)	10253.8053	13306.5665	18456.8499	21406.8827
Trial 2 (N)	N/A	N/A	N/A	N/A
Trial 3 (N)	N/A	N/A	N/A	N/A
Ave(N)	N/A	N/A	N/A	N/A
Mass (g)	57.7	169.5	277.4	211.6
Force/Mass Ratio	**177.7089**	**78.5014**	**66.5351**	**101.1667**
Torque				
	20% Infill	60% Infill	100% Infill	Area Based Variable Infill
Trial 1 (N)	3.1856	7.5712	13.3447	9.8225
Trial 2 (N)	2.6689	6.9865	14.2335	9.2235
Trial 3 (N)	3.2215	8.0068	12.9855	10.3367
Ave(N)	3.025333333	7.5215	13.52123333	9.794233333
Mass (g)	3.3	6.4	10.3	7.4
Force/Mass Ratio	**0.9182**	**1.1719**	**1.3126**	**1.3235**
Tension				
	20% Infill	60% Infill	100% Infill	Area Based Variable Infill
Trial 1 (N)	13.8049	48.9304	69.0245	55.2196
Trial 2 (N)	13.0504	48.0845	68.8674	53.1564
Trial 3 (N)	14.0073	48.4087	68.6843	53.0684
Ave(N)	13.62086667	48.47453333	68.85873333	53.8148
Mass (g)	3.5	8.2	13.4	9.8
Force/Mass Ratio	**3.8914**	**5.9115**	**5.1388**	**5.4898**



5: Conclusions

We designed an algorithm that improved the efficiency of the 3D printing. There has already been research in the field of 3D slicing and object analysis, we believe more work is to be done.

Our area based algorithm, although works, is slow due to the unoptimized code. Not only that, recursive splitting is also a complex task making the algorithm overall quite bloated As already addressed, our algorithm for generative infill designing is innately flawed due to its high complexity. Although there are many algorithms that design infill patterns destructively, a generative method may be faster and more useful.

6: FUrther Research

If we were to conduct further research into this project, we would test the 3D print in real life instead of a physics engine library in order to gauge the practicality of the algorithm especially concerning layer adhesion. With regard to the generative infill algorithm, we also wish to lower the time complexity of the algorithm to polynomial time complexity. Currently the algorithm is exponentially complex because of arches intercepting other arches which creates more arches. Also, we would also look into incorporating deep learning with physics to further our investigations and create a faster and more in-depth algorithm.

7:Bibilography

Achouri, Z., Amroun, N. E., & Benaissa, A. (2016). The Euler-Bernoulli beam equation with boundary dissipation of fractional derivative type. Mathematical Methods in the Applied Sciences, 40(11), 3837–3854. doi: 10.1002/mma.4267

Bayraktar, Ö., Uzun, G., Çakiroğlu, R., & Guldas, A. (2016). Experimental study on the 3D-printed plastic parts and predicting the mechanical properties using artificial neural networks. Polymers for Advanced Technologies, 28(8), 1044–1051. doi: 10.1002/pat.3960

Belter, J. T., & Dollar, A. M. (2014). Strengthening of 3D printed robotic parts via fill compositing. 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems. doi: 10.1109/iros.2014.6942959

Davis, C. S., Hillgartner, K. E., Han, S. H., & Seppala, J. E. (2017). Mechanical strength of welding zones produced by polymer extrusion additive manufacturing. Additive Manufacturing, 16, 162–166. doi: 10.1016/j.addma.2017.06.006

Gagalowicz, A. (n.d.). Morphological modeling and deformation of 3D objects. Proceedings SMI. Shape Modeling International 2002. doi: 10.1109/smi.2002.1003546

Khatwani, J., & Srivastava, V. (2018). Effect of Process Parameters on Mechanical Properties of Solidified PLA Parts Fabricated by 3D Printing Process. 3D Printing and Additive Manufacturing Technologies, 95–104. doi: 10.1007/978-981-13-0305-0_9

Littman, W. (n.d.). Properties of the Euler-Bernoulli beam equation and the Kirchoff plate equation related to controllability. Proceedings of the 28th IEEE Conference on Decision and Control. doi: 10.1109/cdc.1989.70579

Păcurar, R., Păcurar, A., Popister, F., & Popister, A. (2015). Finite Element Analysis to Improve the Accuracy of ABS Plastic Parts Made by Desktop 3D Printing Method. Applied Mechanics and Materials, 760, 509–514. doi: 10.4028/www.scientific.net/amm.760.509

Pande, V., & Nataraj, P. (n.d.). Robust stabilization of Bernoulli-Euler beam by one point feedback. Proceedings of IEEE/IAS International Conference on Industrial Automation and Control. doi: 10.1109/iacc.1995.465833

Papacharalampopoulos, A., Bikas, H., & Stavropoulos, P. (2018). Path planning for the infill of 3D printed parts utilizing Hilbert curves. Procedia Manufacturing, 21, 757–764. doi: 10.1016/j.promfg.2018.02.181

Radenković, G., & Borković, A. (2018). Linear static isogeometric analysis of an arbitrarily curved spatial Bernoulli-Euler beam. doi: 10.31224/osf.io/9rgu6

Sansour, C., Nguyen, T. L., & Hjiaj, M. (2015). An energy-momentum method for in-plane geometrically exact Euler-Bernoulli beam dynamics. International Journal for Numerical Methods in Engineering, 102(2), 99–134. doi: 10.1002/nme.4832

Stava, O., Vanek, J., Benes, B., Carr, N., & Měch, R. (2012). Stress relief. ACM Transactions on Graphics, 31(4), 1–11. doi: 10.1145/2185520.2185544

Torres, J., Cotelo, J., Karl, J., & Gordon, A. P. (2015). Mechanical Property Optimization of FDM PLA in Shear with Multiple Objectives. Jom, 67(5), 1183–1193. doi: 10.1007/s11837-015-1367-y

Tzes, Yurkovich, & Langer. (1989). A method for solution of the Euler-Bernoulli beam equation in flexible-link robotic systems. IEEE International Conference on Systems Engineering. doi: 10.1109/icsyse.1989.48736

Valencia, A. J., Nadon, F., & Payeur, P. (2019). Toward Real-Time 3D Shape Tracking of Deformable Objects for Robotic Manipulation and Shape Control. 2019 Ieee Sensors. doi: 10.1109/sensors43011.2019.8956623

Vanek, J., Galicia, J. A. G., & Benes, B. (2014). Clever Support: Efficient Support Structure Generation for Digital Fabrication. Computer Graphics Forum, 33(5), 117–125. doi: 10.1111/cgf.12437

Vosynek, P., Navrat, T., Krejbychova, A., & Palousek, D. (2018). Influence of Process Parameters of Printing on Mechanical Properties of Plastic Parts Produced by FDM 3D Printing Technology. MATEC Web of Conferences, 237, 02014. doi: 10.1051/matecconf/201823702014

Wang, H. (n.d.). Asymptotic analysis of eigenfrequencies of Euler-Bernoulli beam equation with structural damping. Proceedings of the 28th IEEE Conference on Decision and Control. doi: 10.1109/cdc.1989.70526

Wiebe, M., Rocklin, M., Alumbaugh, T., & Terrel, A. (2014). Blaze: Building A Foundation for Array-Oriented Computing in Python. Proceedings of the 13th Python in Science Conference. doi: 10.25080/majora-14bd3278-00f

Wu, J., Aage, N., Westermann, R., & Sigmund, O. (2018). Infill Optimization for Additive Manufacturing—Approaching Bone-Like Porous Structures. IEEE Transactions on Visualization and Computer Graphics, 24(2), 1127–1140. doi: 10.1109/tvcg.2017.2655523

Zhao, Y., Chen, Y., & Zhou, Y. (2019). Novel mechanical models of tensile strength and elastic property of FDM AM PLA materials: Experimental and theoretical analyses. Materials & Design, 181, 108089. doi: 10.1016/j.matdes.2019.108089

Zhou, Y., Kalogerakis, E., Wang, R., & Grosse, I. R. (2016). Direct shape optimization for strengthening 3D printable objects. Computer Graphics Forum, 35(7), 333–342. doi: 10.1111/cgf.13030