Optimal motion planning for FDM 3D printers

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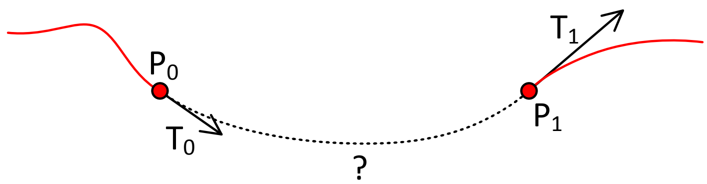
1 Research topic

3D printing recently became widely available, as the cost of printers and materials has been driven down by the maker movement and FabLabs (see an example of printer inset).

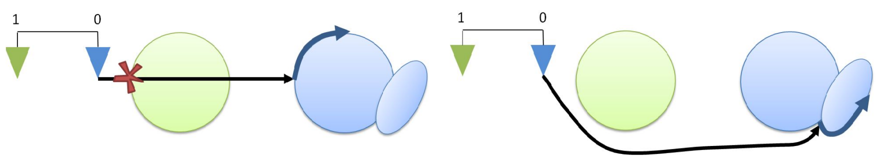
This was accompanied by open source software efforts to provide users with tools to prepare instructions for printers and to control the printer motion from these instructions (firmware). Interestingly, this also revealed some open questions regarding how to best perform these tasks, and a renewed interest in the research community for the related geometric and algorithmic problems. Our team has recently contributed several novel algorithms to help modeling and prepare parts for 3D printing[1, 2, 3, 4]. We are now investigating issues which are closely related to the 3D printing process and in particular the motion of the printing device, with a focus on filament printers (but similar problems are found across different technologies).

Filament 3D printers manufacture an object by depositing melted plastic in layers, from bottom to top. Models are manufactured by moving the nozzle, which deposits filament, along pre-computed printing paths. After finishing printing one path, the extruder moves to the next (this is called a travel move as no material is deposited). This is illustrated in the figure below:



where P_0 and T_0 are the position and speed at the end of last printing path, P_1 and T_1 are the desired position and speed at the start of next printing path. The dashed curve represents the motion from P_0 to P_1 and is unknown – a key question is to determine its optimal parameters – knowing that the end motion is performed by a discrete mechanical device (stepper motors).

While we seek to minimize travel time, the moving speed varies significantly with the curve shape as the acceleration is restricted by mechanical limitations. Other constraints can also be considered, for example the collision with existing prints should be avoided [3], which is illustrated in the figure below:



The overall goal of this research is to consider optimal motion planning for 3D printing, given the geometry of the printing paths. The order, start/end points and travel moves are free variables. We will focus on several aspects:

- Designing travel motion curves with theoretically optimal motion speed.
- Specifying the instructions for stepper motors that will give the maximum speed along the curves.
- Optimizing globally for start/end points along cyclic print paths to accelerate the entire process.

This will reduce the total printing time for filament 3D printers, and has both great theoretical and practical values.

This internship will include three phases:

- Survey on previous work in related areas, for example: CNC path planning, CAD, additive manufacturing, motion planning in robotics.
- Derivation of theoretical equations and formula.
- Implementation and embedding in IceSL [4] and experimental printer firmware.

We will print and measure results on a range of 3D printers available in the lab.

2 Requisites

- Strong programming skills (C++ and/or Python).
- Strong basis in Mathematics, especially in geometry.
- Willingness to confront theory to practical implementations.
- Highly proficient in spoken and written English.

References

[1] T. Reiner, N. Carr, R. Měch, O. Šťava, C. Dachsbacher, and G. Miller, "Dual-color mixing for fused deposition modeling printers," in *Computer Graphics Forum*, vol. 33, pp. 479–486, Wiley Online Library, 2014.

[2] H.-C. Song, N. Ray, D. Sokolov, and S. Lefebvre, "Anti-aliasing for fused filament deposition," *arXiv preprint arXiv:1609.03032*, 2016.

[3] J. Hergel and S. Lefebvre, "Clean color: Improving multi-filament 3d prints," in *Computer Graphics Forum*, vol. 33, pp. 469–478, Wiley Online Library, 2014.

[4] `http://www.loria.fr/~slefebvr/icesl/`.