# 进展报告

## Goal

为了提高FDM打印模型的强度，我们优化填充方式，实现平面内连续打印并保证拐点少，同时将平面内的连续费马螺线填充映射到曲面当中。将生成的轮廓路径转化为对应的G-code，包括生成预处理代码和后处理代码。主要目标为：

1. 生成连续的费马螺线填充;
2. 生成对应的G-code，包含预处理代码、打印路径代码和后处理代码;打印填充平面
3. 自由曲面当中的连续填充。

## Proposed Strategies

1. 为了生成连续的填充方式，我们考虑生成连续费马螺线轮廓来填充。我们同样依据模型外轮廓利用轮廓平行算法得到相应的轮廓平行填充，但轮廓平行填充轮廓之间相互独立、不相连接，不利于模型的强度，故对其进行路径重新规划：不同于who的处理方式我们根据奇偶层分别生成单向螺线，随后将其连接，并且保证方向为单向进出，即实现连续费马螺线填充。
2. G-code

根据材料和硬件设备生成相应的预处理代码和后处理代码，包括挤出丝材的宽度、热床和喷头温度等。同时依照所得连续费马螺线的轮廓路径点生成对应的打印路径。代码中设置相关的偏移量和挤出量参数影响打印过程中轮廓的紧密程度以及费马螺线是否会相互干涉。

1. 曲面映射

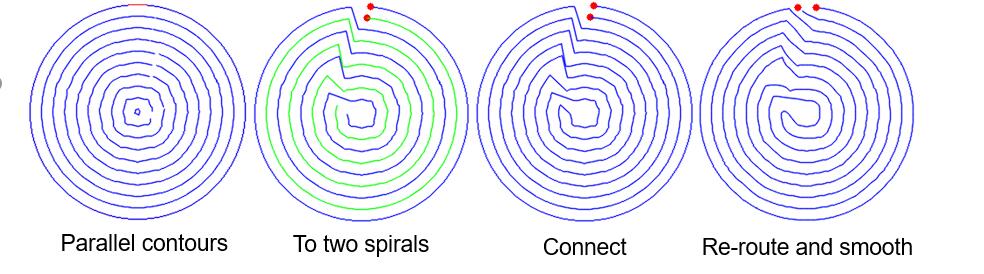
简单圆柱面的映射自由曲面映射为平面，填充平面，随后映射回自由曲面形成曲面连续填充。同时考虑自由曲面的映射，包括近似展开方法和NURBS展开方法。

## Achieved

1. 螺线轮廓和连续费马螺线轮廓

输入STL模型，我们依据模型轮廓利用轮廓平行算法生成了轮廓填充，随后通过路径规划得到了单螺线填充和连续费马螺线填充，保证了打印丝材的连续性，同时减少了填充轮廓的拐点数目和道具空行程，相较于传统zigzag填充减少了材料累积影响的模型强度问题。

在路径重规划中我们设置了打印的起始，寻找到每层的终止点与下一层相连，连接最终的相邻两层的终止点得到连续费马螺线轮廓。



2、输出G-code以及参数的调整

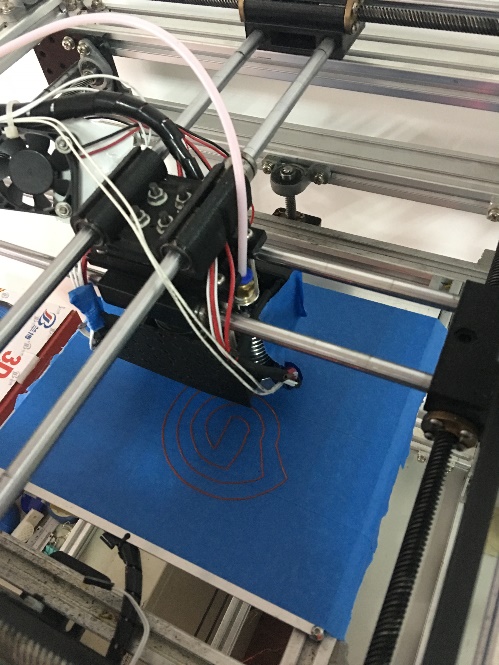
G-code：利用已有G-code和硬件设备，设置相应参数得到G-code前处理和后处理代码。利用前文所述的连续费马螺线轮廓输出相应X，Y坐标得到G-code。输出的G-code用于打印制造。

参数调整：生成费马螺线与生成轮廓平行时的偏移量offset有关，offset值较大多层轮廓之间的距离大，稀疏填充但是强度太差；offset值较小会导致丝材之间粘连，同时可能会对费马螺线轮廓之间连接产生干涉。故我们考虑丝材本身的直径以及其在热床上的宽度来选择合适的偏移量。

在G代码生成中E为两点之间丝材的挤出量，在本文中选用绝对值，E值的选定与两点之间的距离成一定的比例。如两点A（x1,y1）、B(x2,y2)，其间的距离与两点设置的绝对挤出量E1，E2的关系为如下公式。E值太小则会导致出丝量不够，挤出丝材过细从而影响打印强度；E值太大则会破坏层之间的轮廓，甚至。根据测试中的打印表现选择相应的E值。

打印过程和结果如下列图。调整了offset值之后费马螺线之间的连接未受到干涉，同时因为代码中的平滑处理，轮廓之间的连接过度较为平滑，但局部仍然存在填充不足、丝材稀疏的现象。

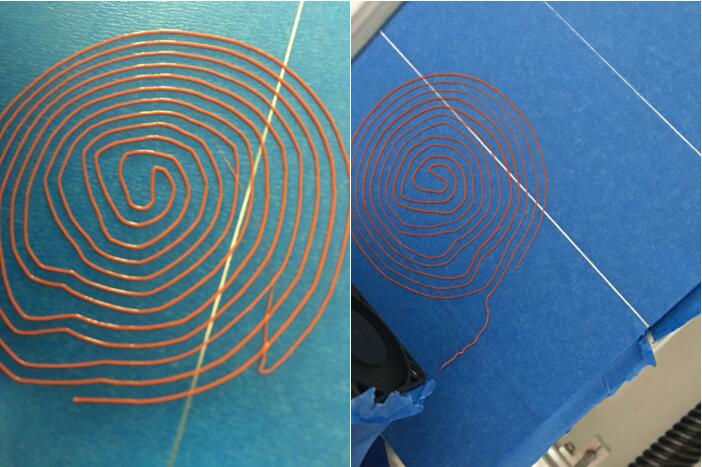




打印过程



单层稀疏填充



单层密集填充

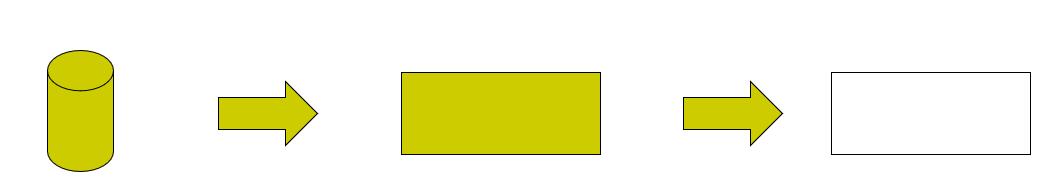
3、曲面映射

根据曲面理论，三维曲面可分为平面、直纹面和空间曲面。根据曲面的可展性又可分为可展曲面和不可展曲面。可展曲面是高斯曲率处处为零的曲面，常见的单参数平面族的包络面是可展曲面,但是如果用双参数来设计曲面，则很难满足可展性。空间曲面映射为平面的精度可以通过以下几个指标衡量：相对面积误差、相对角度误差、相对长度误差。因此映射可以大致分为1、等角映射2、等面积映射3、任意映射4、特殊点映射5、等距映射。

我们需要将空间曲面映射为平面，随后利用连续费马螺线填充二维平面，根据曲面和平面之间的相互关系转化为曲面中的连续费马螺线填充。

空间曲面可以映射到可展曲面上，随后展开相应的可展曲面。几种近似展开方法：单圆锥映射法、多圆锥逼近法、圆柱映射法。圆柱映射法：假定以圆柱面作为映射，把空间曲面映射到圆柱面，然后依照上述过程中展开圆柱面形成平面。

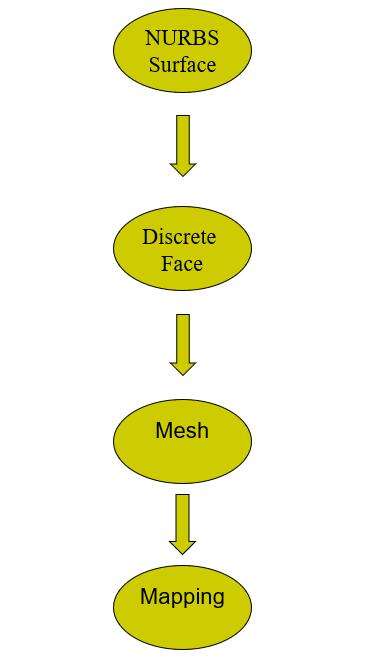
考虑简单的圆柱面的曲面填充形式，对于圆柱面其展开为长方形，我们利用长方形外轮廓生成连续费马螺线。



自由曲面的填充：曲面映射时其上点的相互位置总是要发生变动，曲面上的几何特性曲线长度、方向和曲面面积受到破坏。

NURBS曲面的平面映射：NURBS曲面对标准曲线、曲面和自由线、曲面提供了统一的数学参数表示;而且可以通过权因子和控制点来灵活地改变曲面的形状;个别控制顶点和权因子的调整只影响曲面的局部。利用这些特点, 可以用它构造各种复杂的曲面造型和表面特殊的效果。

NURBS曲面为不可展曲面，不可展曲面的展开有以下几种方法：几何展开法、力学展开法和几何展开力学修正法。为了将其映射到平面上，需要将自由曲面离散成多个面片，即对曲面进行网格划分。离散后的曲面通过映射算法映射到平面。



# 附 G-CODE

; external perimeters extrusion width = 0.40mm

; perimeters extrusion width = 0.67mm

; infill extrusion width = 0.67mm

; solid infill extrusion width = 0.67mm

; top infill extrusion width = 0.67mm

M107

M190 S70 ; set bed temperature

M104 S190 ; set temperature

G28 ; home all axes

G1 Z5 F5000 ; lift nozzle

M109 S190 ; wait for temperature to be reached

G21 ; set units to millimeters

G90 ; use absolute coordinates

M82 ; use absolute distances for extrusion

G92 E0

G1 E-3.00000 F1800.00000

G92 E0

G1 Z0.350 F4800.000

G1 X74.800 Y32.200 F4800.000

G1 E3.00000 F1800.00000

G1 X74.800 Y32.200 E3.00000 F600

G1 X76.900 Y32.700 E3.19623

G1 X79.000 Y33.200 E3.39245

G1 X80.800 Y33.800 E3.56492

G1 X82.800 Y34.200 E3.75032

G1 X84.200 Y34.800 E3.88878

G1 X85.600 Y35.200 E4.02113

G1 X86.800 Y35.800 E4.14309

G1 X88.000 Y36.200 E4.25807

G1 X89.200 Y37.000 E4.38916

G1 X90.400 Y37.600 E4.51112

G1 X92.000 Y38.800 E4.69292

G1 X93.600 Y39.800 E4.86443

G1 X95.800 Y41.600 E5.12282

G1 X97.600 Y43.200 E5.34173

G1 X99.800 Y45.400 E5.62455

G1 X101.400 Y47.200 E5.84346

G1 X103.000 Y49.200 E6.07628

G1 X103.800 Y50.600 E6.22285

G1 X104.800 Y52.000 E6.37924

G1 X105.200 Y53.000 E6.47714

G1 X105.800 Y54.000 E6.58315

G1 X106.200 Y55.000 E6.68105

G1 X106.800 Y56.000 E6.78706

G1 X107.200 Y57.000 E6.88496

G1 X107.800 Y58.000 E6.99097

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G1 X107.200 Y92.000 E10.15710

G1 X106.800 Y93.000 E10.25500

G1 X106.200 Y94.000 E10.36101

G1 X105.800 Y95.000 E10.45891

G1 X105.200 Y96.000 E10.56491

G1 X104.800 Y97.000 E10.66282

G1 X103.800 Y98.400 E10.81921

G1 X103.000 Y99.800 E10.96578

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G1 X99.800 Y103.600 E11.41751

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G1 X92.000 Y110.200 E12.34914

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G1 X86.800 Y113.200 E12.89897

G1 X85.600 Y113.800 E13.02093

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G1 X75.400 Y116.200 E13.97886

G1 X72.000 Y116.400 E14.28845

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G1 X35.200 Y97.000 E18.27769

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G1 X34.200 Y95.000 E18.48160

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G1 X59.800 Y106.800 E59.18234

G1 X61.600 Y107.200 E59.34995

G1 X63.600 Y107.800 E59.53975

G1 X66.000 Y108.200 E59.76092

G1 X69.000 Y108.400 E60.03423

G1 X72.200 Y108.400 E60.32511

G1 X75.000 Y108.200 E60.58028

G1 X77.800 Y107.800 E60.83738

G1 X80.000 Y107.200 E61.04466

G1 X81.800 Y106.600 E61.21714

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G1 X92.000 Y99.400 E62.35649

G1 X94.000 Y97.400 E62.61360

G1 X95.600 Y95.600 E62.83251

G1 X97.000 Y93.800 E63.03980

G1 X97.800 Y92.400 E63.18637

G1 X98.800 Y91.000 E63.34276

G1 X99.200 Y90.000 E63.44066

G1 X99.800 Y89.000 E63.54667

G1 X100.200 Y87.600 E63.67902

G1 X100.800 Y86.000 E63.83435

G1 X101.200 Y84.000 E64.01975

G1 X101.800 Y81.800 E64.22704

G1 X102.200 Y78.800 E64.50215

G1 X102.400 Y75.600 E64.79360

G1 X102.400 Y72.400 E65.08448

G1 X102.200 Y69.200 E65.37592

G1 X101.000 Y64.800 E65.79049

G1 X99.400 Y61.000 E66.16528

G1 X97.800 Y57.600 E66.50685

G1 X95.800 Y54.200 E66.86542

G1 X93.600 Y51.200 E67.20359

G1 X91.800 Y49.400 E67.43498

G1 X90.000 Y47.800 E67.65390

G1 X88.200 Y46.400 E67.86118

G1 X86.400 Y45.200 E68.05783

G1 X84.800 Y44.200 E68.22934

G1 X83.200 Y43.400 E68.39194

G1 X81.800 Y42.800 E68.53040

G1 X80.200 Y42.200 E68.68573

G1 X78.400 Y41.800 E68.85334

G1 X76.400 Y41.200 E69.04315

G1 X73.400 Y39.200 E69.37089

G1 X70.100 Y37.100 E69.72645

G1 E6.95908 F1800.00000

G92 E0

M104 S0 ; turn off temperature

G28 X0 ; home X axis

M84 ; disable motors

; filament used = 148.9mm (0.4cm3)

; avoid\_crossing\_perimeters = 0

; bed\_shape = -100x-100,100x-100,100x100,-100x100

; bed\_temperature = 10

; before\_layer\_gcode =

; bridge\_acceleration = 0

; bridge\_fan\_speed = 100

; brim\_width = 0

; complete\_objects = 0

; cooling = 1

; default\_acceleration = 0

; disable\_fan\_first\_layers = 1

; duplicate\_distance = 6

; end\_gcode = M104 S0 ; turn off temperature

G28 X0 ; home X axis

M84 ; disable motors

; extruder\_clearance\_height = 20

; extruder\_clearance\_radius = 20

; extruder\_offset = 0x0

; extrusion\_axis = E

; extrusion\_multiplier = 1,1

; fan\_always\_on = 0

; fan\_below\_layer\_time = 60

; filament\_colour = #FFFFFF

; filament\_diameter = 1.75,1.75

; first\_layer\_acceleration = 0

; first\_layer\_bed\_temperature = 10

; first\_layer\_extrusion\_width = 200%

; first\_layer\_speed = 30%

; first\_layer\_temperature = 190,190

; gcode\_arcs = 0

; gcode\_comments = 0

; gcode\_flavor = reprap

; infill\_acceleration = 0

; infill\_first = 0

; layer\_gcode =

; max\_fan\_speed = 0

; max\_print\_speed = 60

; max\_volumetric\_speed = 0

; min\_fan\_speed = 35

; min\_print\_speed = 10

; min\_skirt\_length = 0

; notes =

; nozzle\_diameter = 0.4

; only\_retract\_when\_crossing\_perimeters = 1

; ooze\_prevention = 0

; output\_filename\_format = [input\_filename\_base].gcode

; perimeter\_acceleration = 0

; post\_process =

; pressure\_advance = 0

; resolution = 0

; retract\_before\_travel = 2

; retract\_layer\_change = 1

; retract\_length = 3

; retract\_length\_toolchange = 10

; retract\_lift = 0

; retract\_restart\_extra = 0

; retract\_restart\_extra\_toolchange = 0

; retract\_speed = 30

; skirt\_distance = 6

; skirt\_height = 1

; skirts = 1

; slowdown\_below\_layer\_time = 30

; spiral\_vase = 0

; standby\_temperature\_delta = -5

; start\_gcode = G28 ; home all axes

G1 Z5 F5000 ; lift nozzle

; temperature = 190,190

; threads = 2

; toolchange\_gcode =

; travel\_speed = 80

; use\_firmware\_retraction = 0

; use\_relative\_e\_distances = 0

; use\_volumetric\_e = 0

; vibration\_limit = 0

; wipe = 0

; z\_offset = 0

; dont\_support\_bridges = 1

; extrusion\_width = 0

; first\_layer\_height = 0.35

; infill\_only\_where\_needed = 0

; interface\_shells = 0

; layer\_height = 0.2

; raft\_layers = 0

; seam\_position = aligned

; support\_material = 0

; support\_material\_angle = 0

; support\_material\_contact\_distance = 0.2

; support\_material\_enforce\_layers = 0

; support\_material\_extruder = 1

; support\_material\_extrusion\_width = 0

; support\_material\_interface\_extruder = 1

; support\_material\_interface\_layers = 3

; support\_material\_interface\_spacing = 0

; support\_material\_interface\_speed = 100%

; support\_material\_pattern = pillars

; support\_material\_spacing = 2.5

; support\_material\_speed = 60

; support\_material\_threshold = 90

; xy\_size\_compensation = 0

; bottom\_solid\_layers = 3

; bridge\_flow\_ratio = 1

; bridge\_speed = 60

; external\_fill\_pattern = rectilinear

; external\_perimeter\_extrusion\_width = 0

; external\_perimeter\_speed = 70%

; external\_perimeters\_first = 0

; extra\_perimeters = 1

; fill\_angle = 45

; fill\_density = 20%

; fill\_pattern = honeycomb

; gap\_fill\_speed = 20

; infill\_every\_layers = 1

; infill\_extruder = 1

; infill\_extrusion\_width = 0

; infill\_overlap = 15%

; infill\_speed = 60

; overhangs = 1

; perimeter\_extruder = 1

; perimeter\_extrusion\_width = 0

; perimeter\_speed = 30

; perimeters = 3

; small\_perimeter\_speed = 30

; solid\_infill\_below\_area = 70

; solid\_infill\_every\_layers = 0

; solid\_infill\_extruder = 1

; solid\_infill\_extrusion\_width = 0

; solid\_infill\_speed = 60

; thin\_walls = 1

; top\_infill\_extrusion\_width = 0

; top\_solid\_infill\_speed = 50

; top\_solid\_layers = 3