Select an Optimal Printing Orientation
Based on Particle Swarm Optimization

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Abstract

To ensure the model not damaged when fabricating a model in 3D printing, the support structure is designed and need to be cleared after fabrication, which consumes many materials and adds the manufacturing complexity. Therefore, a strategy to determine the printing orientation which minimizes the supporting area is necessary. In this paper, we propose a strategy to generate approximately optimal printing orientation to minimize the supporting area. Since this optimal problem is not an convex optimization problem, the accurate solution is not guaranteed to be found. Here the Particle Swarm Optimization Algorithm is applied to find the approximately optimal solution. The numerical experiment shows that our strategy can determine the approximately optimal printing orientation efficiently. The code is available on github.com/sunyasheng/Computer-Graphics.

Keywords: minimum supporting area, particle swarm optimization, optimal printing orientation

Introduction

Particle Swarm Optimization(PSO) is a computational method that finds a solution by iteratively improving a candidate solution, which is broadly applied to the problems whose exact solution are impossible to compute, specifically nonlinear optimization problems.

PSO is firstly introduced to simulate social behavior but finally became an optimization paradigm to perform optimization in complex situations. PSO have the following advantages: 1) it makes few assumptions and is capable of searching solutions in a very large state space. 2) it does not require the problem to be differentiable like other optimization paradigm such as gradient descent. However, it does not guarantee that an optimal solution is found.

Methodology

In this section, a novel printing orientation selection strategy using Particle Swarm Optimization is developed. Each particle in the particle swarm optimization represents a solution, which is a printing orientation in this problem. Its value is evaluated through computing the support area in this orientation. All the particles cooperate to find the optimal solution following certain rule according to the computed value. The whole work flow is described in Fig. 1.

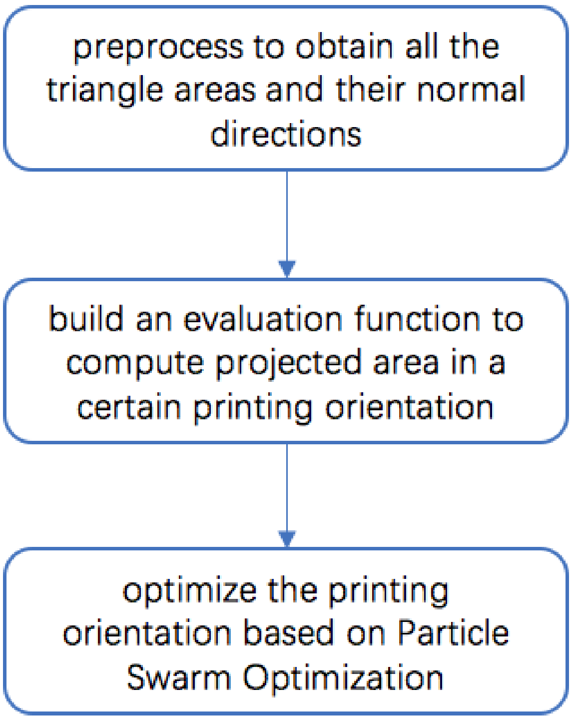

Fig. 1. Work flow

Particle Swarm Optimization

Simulating the food seeking process of flock, PSO firstly initialize many particles representing solutions and update those particles iteratively according to the PSO updating rule shown in Fig.2. p_1 indicates the best solution in history for each particle while p_2 indicates best solution of all particles. Updating is divided into two stages. The velocity reflecting the inertia towards better solution is computed and then it is added to the previous position of each particle. a, b, c, d, r_1, and r_2 are all coefficients affecting this updating process.

$$v_{k+1} = av_k + b_1 r_1 (p_1 - x_k) + b_2 r_2 (p_2 - x_k),$$

$$x_{k+1} = cx_k + dv_{k+1}.$$

Fig. 2. PSO Updating Rule

Computation of Support Area in a Certain Orientation

If the model is represented by mesh, the support area is the total area of the facets whose normal direction between downward direction is less than 45 deg. The optimal printing orientation corresponds to a specific position of the model in the world coordinate. Since the translation does not affect the support area, only the rotation including three degree of freedom is considered. The formula to compute the support area in a certain orientation is shown in in Fig. 3. The support area simply sums all the projected area along the downward direction e_d only when the angle between triangles' normal direction and downward direction is less than 45 deg. The normal direction of each triangle is denoted by e_n. The downward direction is denoted by e_d. Our task is finding an optimal downward direction e_d to minimize the support area.

$$SupportArea = \sum_{i=1}^{n} area_i \times cos < e_n, e_d > if(0 \leq cos < e_n, e_d >< \frac{\sqrt{2}}{2})$$

Fig. 3. Support Area Computation

Optimal Printing Orientation Selection Strategy

In this problem, each particle is a vector $e_n = (\alpha, \beta, \gamma)^T$ represents the downward direction. The solution space is explored following updating rule in Fig. 1. The procedure is described below.

Algorithm 1 PSO(ParticleNumber N, IterationNumber K)

Initialize N paricles randomly $x_1, x_2, ..., x_N$
Initialize the best postion $pbest_1 = x_1, pbest_2 = x_2, ..., pbest_N = x_N$
Compute the value $v_1, v_2, ..., v_3$
Initialize the best value $vbest_1 = v_1, vbest_2 = v_2, ..., vbest_N = v_N$
Initialize the global maximum value MaxValue and global best position gbest
for $iter = 1$**to**K **do**
  for *Each particle* $i = 1$**to**N **do**
    Compute the value v_i
    if $vbest_i < v_i$ **then**
      $pbest_i \leftarrow x_i, v_i \leftarrow vbest_i$
      if $MaxValue < pbest_i$ **then**
        $MaxValue \leftarrow pbest_i, gbest \leftarrow pbest_i$
      end if
    end if
  end for
  for *Each Particle* $i = 1$**to**N **do**
    $velocity_i \leftarrow av_i + b_1 r_1 (pbest_1 - x_1) + b_2 r_2 (gbest - x_i)$
    $x_i \leftarrow cx_i + d\ velocity_i$
  end for
end for

Numerical Experiment

We initialize 50 particles and iterate for 15 times in this problem. The minimum support area in different iteration is shown in Fig. 4.

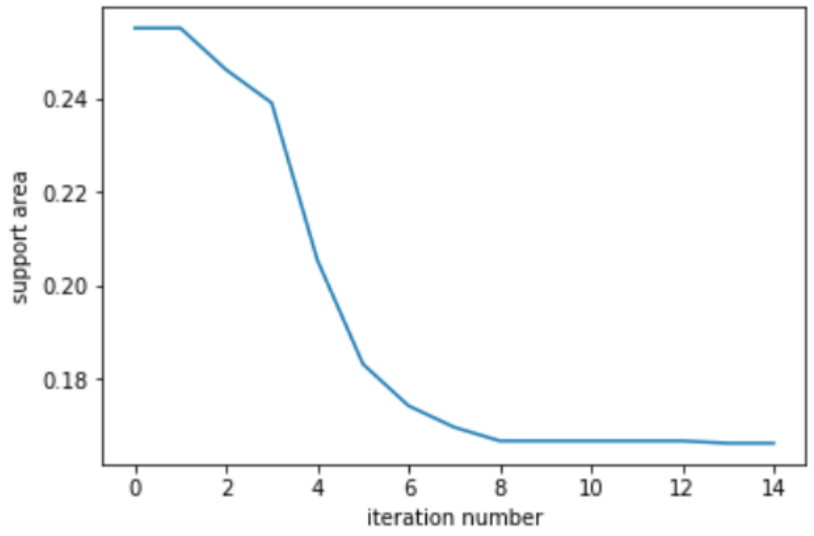

Fig. 4. Support Area

The details of orientation optimization is shown in Fig. 5. The best downward direction is $(0.754, -0.623, -0.207)^T$ and the support area under this direction is 0.1662.

```
INFO:pyswarms.single.global_best:Iteration 1/15, cost: 0.255144481322
INFO:pyswarms.single.global_best:Iteration 3/15, cost: 0.246242846445
INFO:pyswarms.single.global_best:Iteration 5/15, cost: 0.205484061733
INFO:pyswarms.single.global_best:Iteration 7/15, cost: 0.174235071168
INFO:pyswarms.single.global_best:Iteration 9/15, cost: 0.16671985875
INFO:pyswarms.single.global_best:Iteration 11/15, cost: 0.16671985875
INFO:pyswarms.single.global_best:Iteration 13/15, cost: 0.16671985875
INFO:pyswarms.single.global_best:Iteration 15/15, cost: 0.166223849553
INFO:pyswarms.single.global_best:================================
Optimization finished!
Final cost: 0.1662
Best value: [0.75406267706824437, -0.62340991869756435, -0.20675964867973884]
```

Fig. 5. Details of Optimization

Conclusion

In this report, a strategy to select the approximately optimal printing orientation is proposed. This non-convex problem is solved by Particle Swarm

Optimization. Experiment shows that the proposed strategy can determine the orientation efficiently and the found solution is acceptable.

Reference

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