Averaging compatible surfaces for free-form tolerancing

"How to improve your manufacturing accuracy / reliability?"

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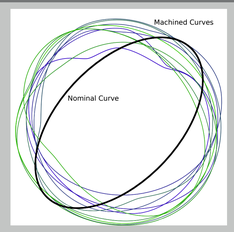
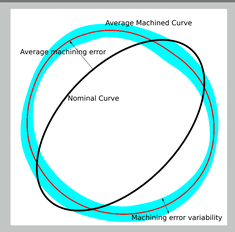
Overview

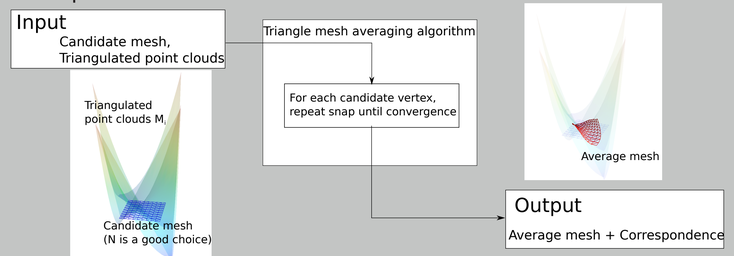
- Inconsistent output $\neq$ Consistently bad output.
  - There are consistent & inconsistent machining errors.
- Analyzing average error and error variability separately facilitates decision making.
  - Nominal $\neq$ Average : Better plan?
  - Variability $>$ Maximum : Better machine?





Computing average and variability

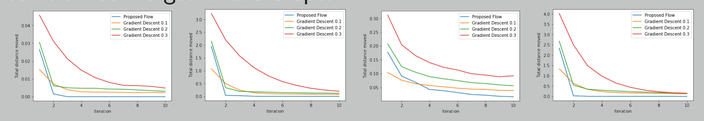
- Input: Nominal shape N, machined shapes M_i.
- Output: Average mesh, variability.
- Algorithm:
  - Sample M_i to obtain machined shapes point clouds.
  - Filter and register point clouds.
  - Triangulate each point cloud. :item Compute average triangle mesh and correspondences:



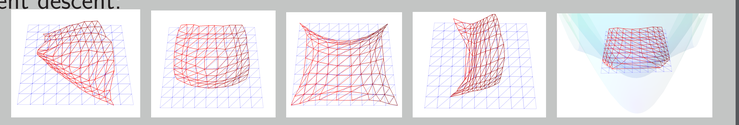
  - Compute variability from correspondences.

Results

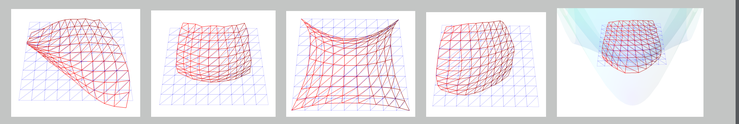
- Comparison with gradient descent:
  - Snap iteration converges in 2-3 steps.



  - Snap iterations produce low distortions.
    - Gradient descent:



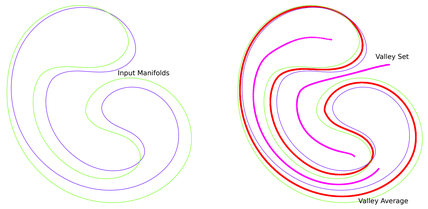
    - Snap:



Salient details

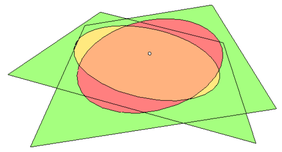
Compatible smooth manifolds and the Valley Average

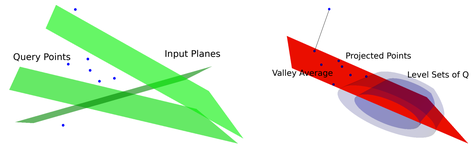
- Set of embedded manifolds compatible if pairwise closest projection maps are homeomorphisms.
- A compatible set has a natural average - the valley average - a connected subset of points that lie on the valley of the sum of squared distance field Q.



Averaging planes

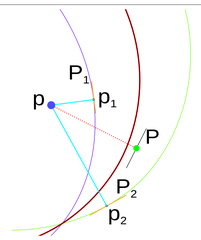
- Planes compatible when hessian of Q is a positive definite quadratic form.
- Valley average of a set of planes is a plane.
  - Coincident planes:
    - Average is coincident.
    - Maximizes sum of unit circle projection areas.
  - Non-coincident planes:
    - Average directed as coincident case
    - Incident to point minimizing Q.
- Numerically robust formula to project on average.





Snap iterations

- A snap iteration comprises:
  - Closest project: Given candidate point p, compute closest projection to i^{th} mesh p_i.
  - Average computation: Compute average plane P using tangent plane approximation P_i at p_i.
  - Projection on average plane: Project p onto P.



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