Topology Preserving Fitting of Trimmed NURBS CAD Model to Deformed Solids

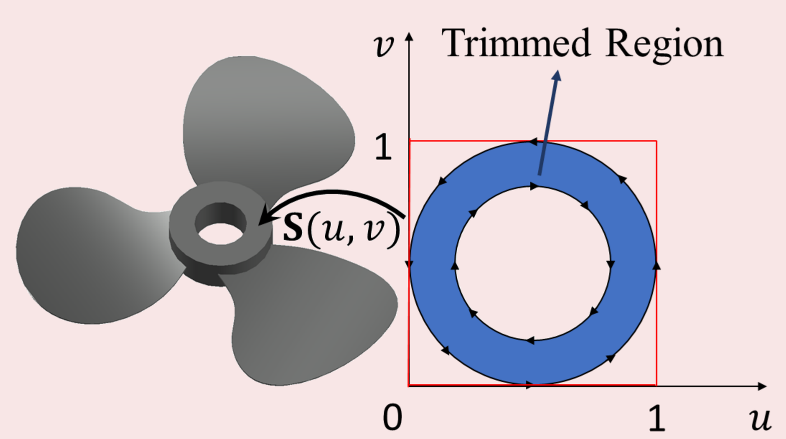
IOWA STATE UNIVERSITY

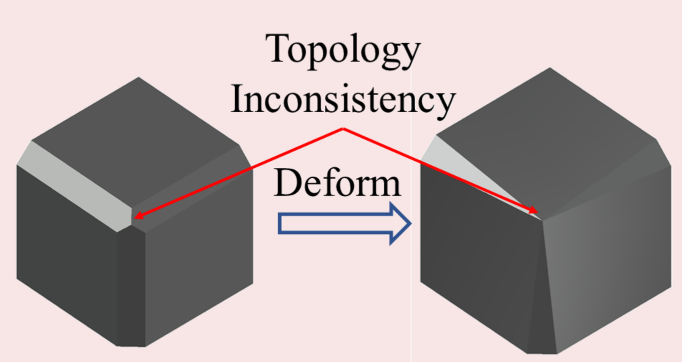
Lijie Liu, Weijun Shen, Zhan Zhang, Stephen D. Holland, Adarsh Krishnamurthy, Qing Li

Center for Nondestructive Evaluation - CNDE

Introduction

- **Digitalization** is the process of use virtual representation of physical product.
- **Geometry deviation** exits between the as-designed CAD model and the finished products still exist in many situations.
- **NURBS** is the de-facto representation of 3D geometry in the CAD system. The **trimmed** NURBS are more powerful in presenting complex geometry.
- **Mapping** between the as-designed CAD and as-built geometry provides a deeper understanding of manufacturing systems and facilitates improving the quality of the parts. Reverse engineering **does not** create such mapping.
- **Objective** is to propose a systematic framework for gap-free fitting the as-designed CAD model to the as-built geometry.
- **Highlight**: 1) Developed the constraints to retain the intersection in the parametric space of the trimmed NURBS surfaces for **preserving the topology**. 2) Proposed CADConform framework to create such mapping by optimizing the NURBS parameters of as-designed CAD model.





Methodology

- Optimize the location of control points to fit the geometry by minimizing the objective function
$$\min_{\boldsymbol{P}} L(\boldsymbol{P}) = \lambda_{CD} L_{CD}(\boldsymbol{P}) + \lambda_{HD} L_{HD}(\boldsymbol{P})$$
- Preserve the topology and gap-free connection by constraints
$$\boldsymbol{S}_A(\boldsymbol{C}_A(t_A)) = \boldsymbol{S}_B(\boldsymbol{C}_B(t_B)) \qquad t_A, t_B \in [0,1]$$
- Discretize the constraints to solve the semi-infinite problem
$$\boldsymbol{S}_A(\boldsymbol{P}_A; \mu_A^k, v_A^k) = \boldsymbol{S}_B(\boldsymbol{P}_B; \mu_B^k, v_B^k)$$
- Approximate the loss function by calculating the loss between evaluation points from the CAD and the measured point cloud. And solve the constrained optimization problem using Projected gradient descent

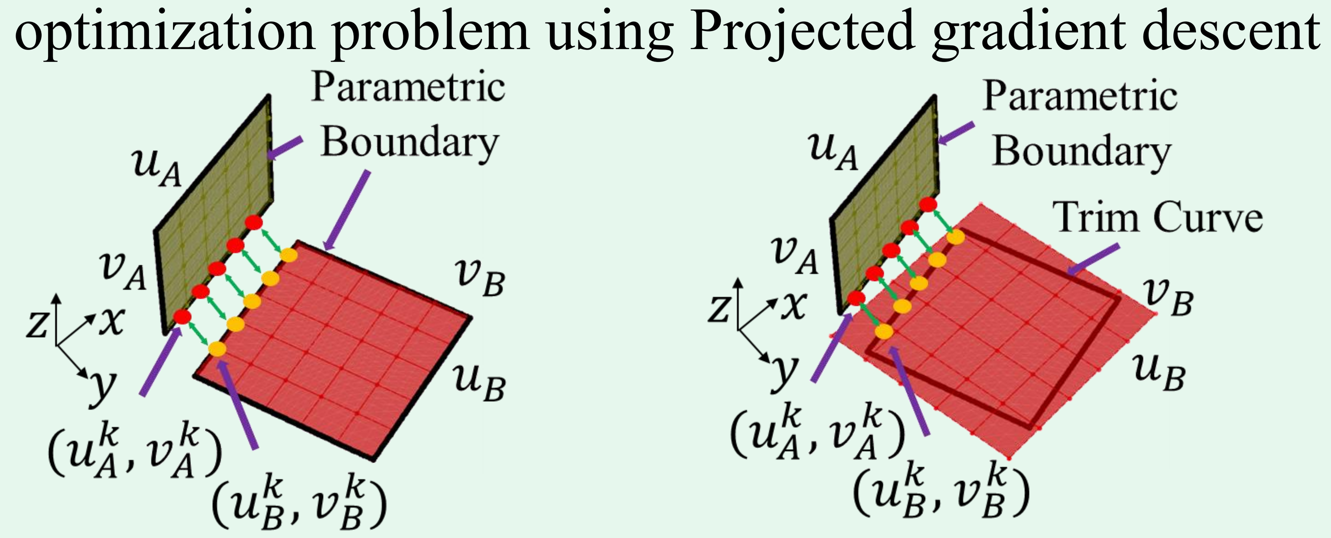
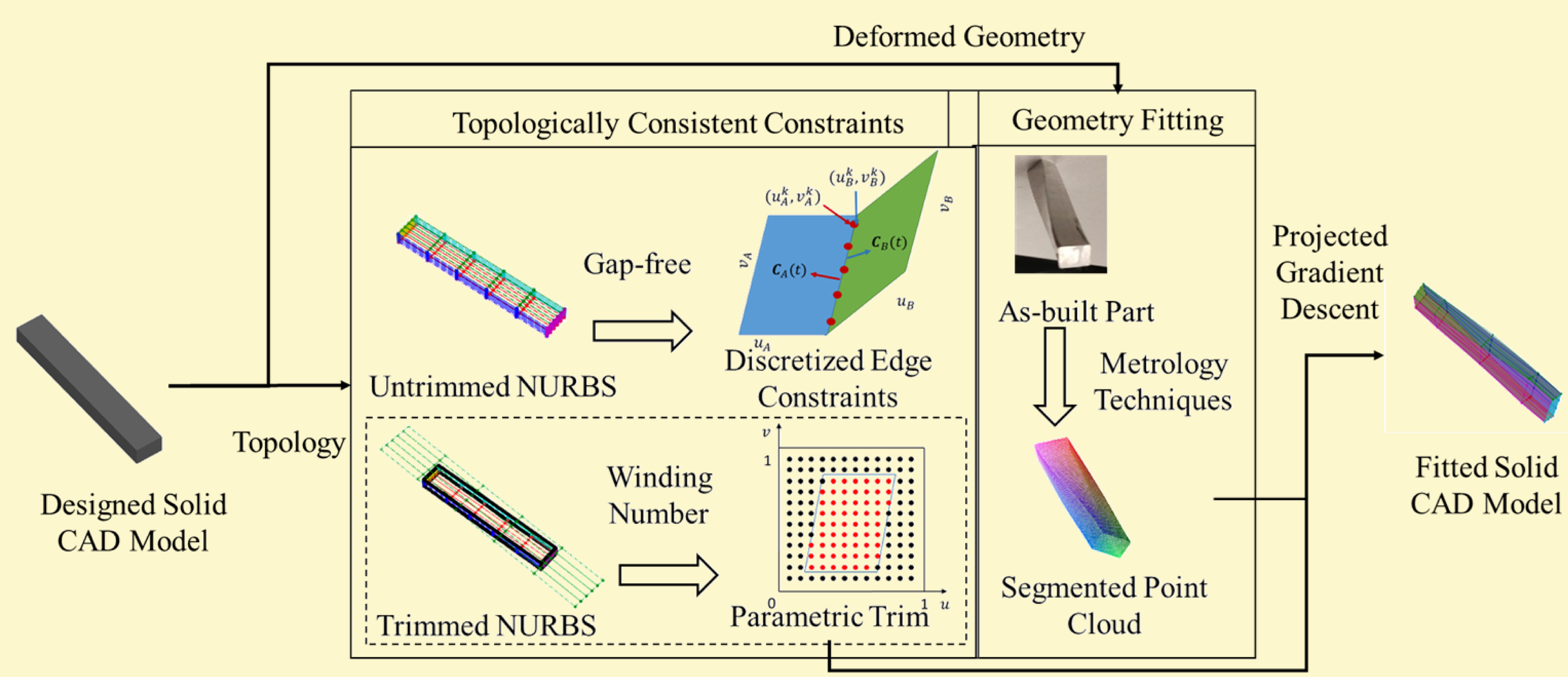


Figure 1: The illustration of constraints for untrimmed (left) and trimmed (right) surface



Analysis and Results

- The CAD model shows almost a same geometry as the point cloud as we find that normalized chamfer distance is less than 1%.
- The CAD model is gap-free with a consistent topology to the designed bar CAD model, since average gap is negligibly small.
- More evaluation points on the surface is beneficial to the fitting results.

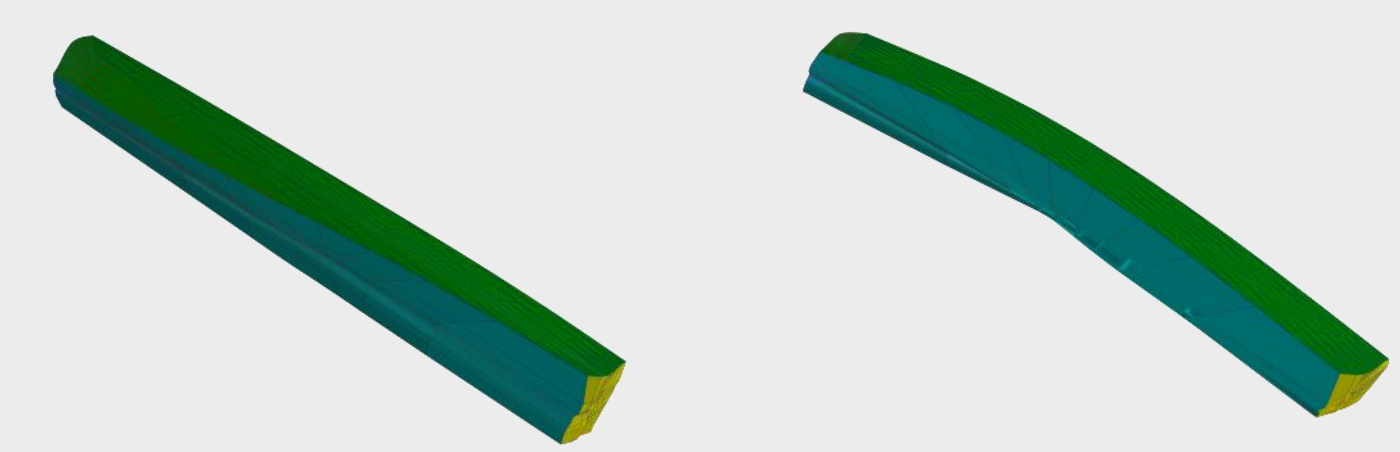


Figure 2: The fitted CAD model for (left) the trimmed twisted bar sample and (right) the trimmed bent bar sample

Part	Chamfer Distance (%)	Hausdorff Distance (%)	Average Gap (%)
Twisted	0.29	3.70	5.36×10^{-3}
Bent	0.31	4.29	6.10×10^{-3}

Table 1: The results for the trimmed surface case study.

# of Evaluation Points	Chamfer Distance (%)	Hausdorff Distance (%)	Average Gap (%)
18	1.66	20.33	1.94×10^{-4}
54	1.02	16.78	1.82×10^{-4}
156	0.76	15.76	1.86×10^{-4}
336	0.64	12.12	1.94×10^{-4}
780	0.50	10.47	1.91×10^{-4}

Table 2: The results for the case study with a different number of evaluation points on the top trimmed NURBS surface.

Conclusion

- CADConform: tool for gap-free CAD fitting with a preserved topology based on as-designed CAD model.
- our approach is generalizable because CADConform works for point cloud data acquired from different metrologies.

Acknowledgements