

# Tooth Registration

1. Surface-based Registration
2. Point cloud-based Registration
3. Result and Analysis

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# 1. Surface-based Registration (Previous Method)

- **Procedure**

- Scan the tooth with 3D scanner → scan.stl
- Measure multiple points on the tooth with CMM
- Generate surface with the multiple points through inter/extrapolation<sup>1</sup> → measure.stl
- Align the two models / Compute the transformation matrix / Analyze the distance error

- **Limitation**

- CMM measurement noise
- Human error when measuring multiple points with CMM
- inter/extrapolation error of the generated surface
- lack of correspondences for alignment<sup>2</sup>

- **To-do**

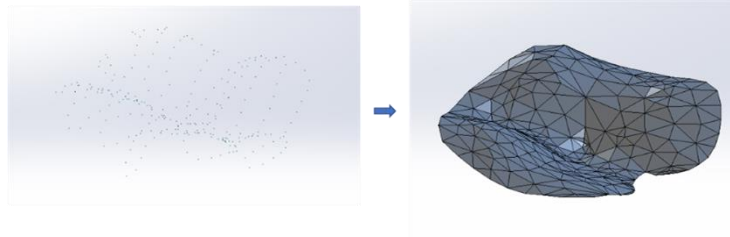
- Measure the small number of points of the unique shape (e.g. valley of tooth)
- Take the various types of noise into account
- Estimate not only the transformation matrix but also correspondences



3D Scanner

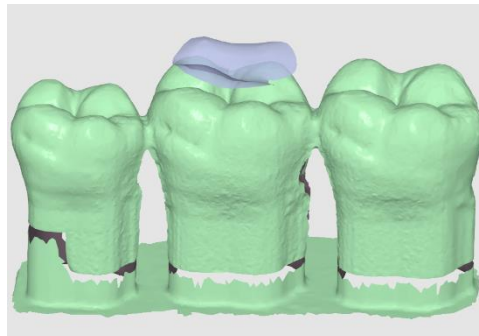


CMM

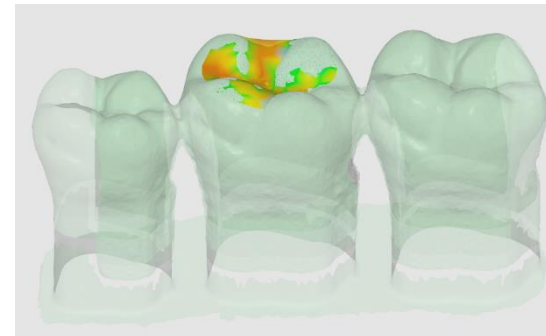


XYZ points

Surface<sup>1</sup>

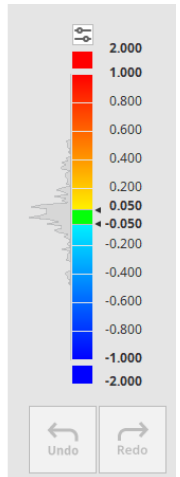


Alignment<sup>2</sup>



Analysis Visualization

Properties	
Min.	-0.463 mm
Max.	0.531 mm
Median	0.035 mm
Avg.	0.051 mm
Abs Avg.	0.132 mm
RMS	0.187 mm
Std. Dev.	0.180 mm
Var.	0.032 mm
Avg.(+)	0.139 mm
Avg.(-)	-0.118 mm
(90-10)/2	0.230 mm
10 Percentile	-0.123 mm
90 Percentile	0.331 mm
In Tol.	32.42 %

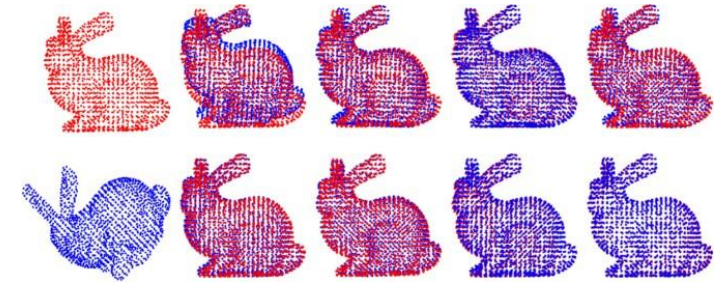


Analysis Statistics

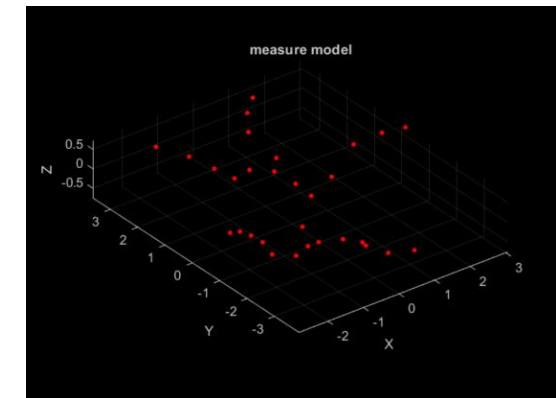
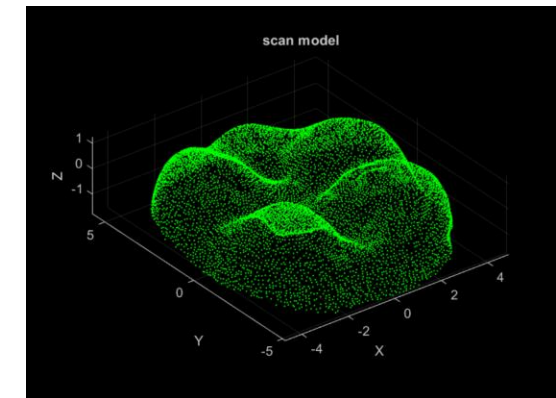
1. inter/extrapolation error: the surface between three points is assumed to be flat triangular plane / 2. Inaccurate Alignment due to the lack of correspondences

## 2. Point cloud-based Registration

- **Overview of Point-set Registration<sup>1</sup>**
  - Correspondence-based Registration
    - : Outlier-free registration, Robust registration, ...
  - Simultaneous Pose and Correspondence Registration
    - : Iterative Closest Point (ICP), Coherent Point Drift (CPD), Normal Distribution Transformation (NDT),...
- **NDT for our application**
  - Rigid-body transformation
  - Correspondence registration
  - Probability-based registration
    - : the noise of measurement may have normal distribution
- **Procedure**
  - Convert 3D scan model to point clouds
  - Measure points only on the valley of the tooth with CMM
  - Point cloud-based registration (NDT)
  - Compute the transformation matrix / Analyze the distance error
- **Limitation**
  - The results are dependent on initial guess of correspondences

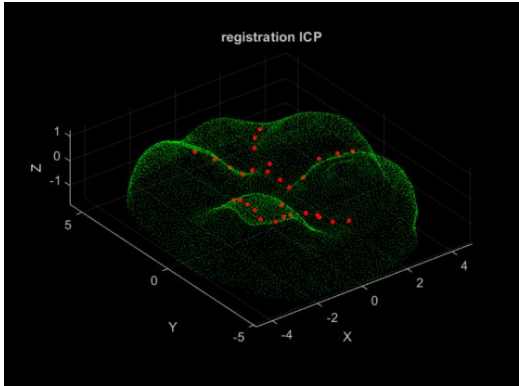
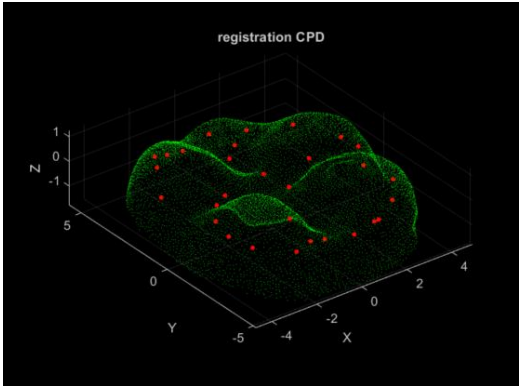
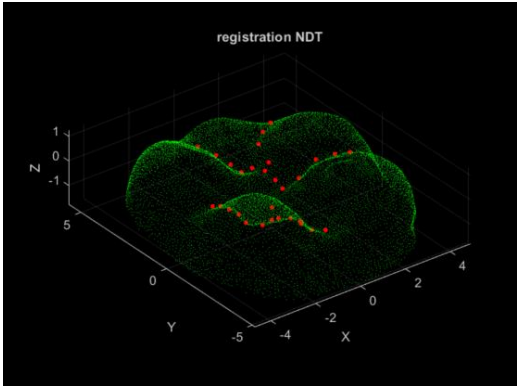
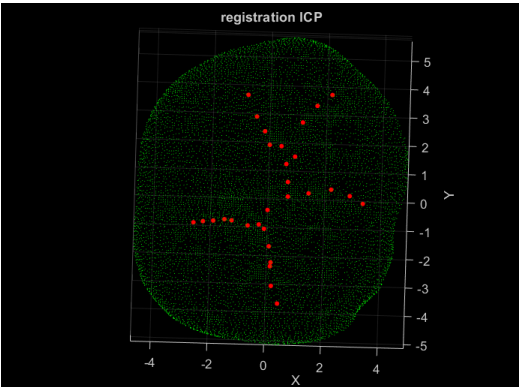
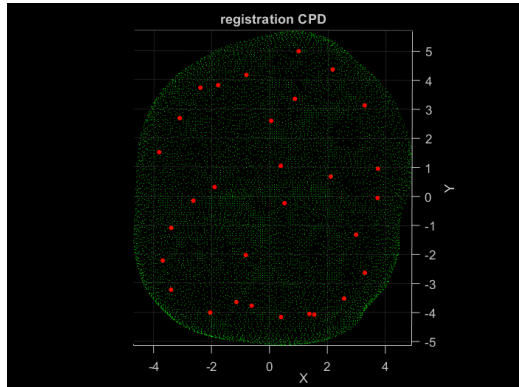
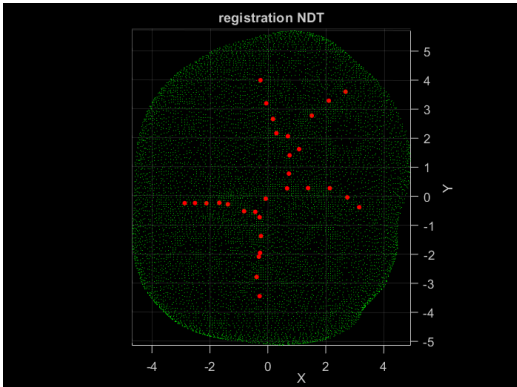


Example of Point-set Registration



Point Clouds of Scan/Measure Model

3. Result & Analysis

	ICP	CPD	NDT
Probabilistic	X (Deterministic)	O	O
Rigid Transformation	O	X (Non-rigid)	O
Correspondence Estimation	O	O	O
Figure			
			
RMSE (mm)	0.3398	0.1085	0.0679