ARIZONA STATE UNIVERSITY

A Robust Registration Algorithm for Automatic and Reliable Geometric Change Detection of Bridges using 3D Laser Scanning Data

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Presenter

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What are Geometric Changes on a Bridge ?

Fatigue Crack

*http://www.mdpi.com/2075-5309/2/4/456/htm

Irregular Settlement

*https://www.slideshare.net/rahulmatariya/defects-in-bridges

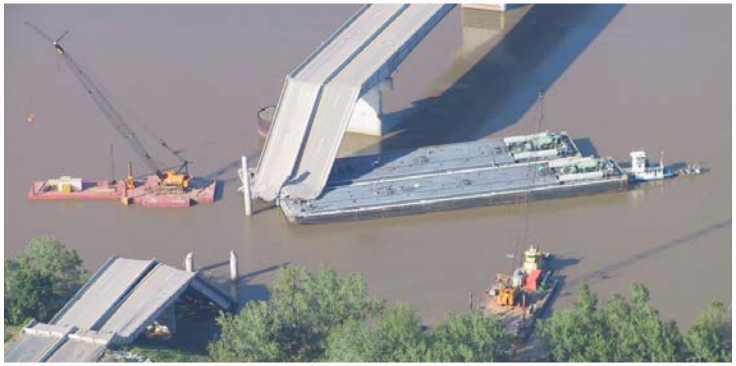
Geometric Changes:

Geometric Deviations during the service life of the bridge structure such as rigid body **motions** and **deformations** of individual elements of the bridge structure etc.

Why Tracking Geometric Changes Important ?

Damaged Pfeiffer Canyon Bridge

https://www.sott.net/article/343726-Bridge-damage-severs-Big-Surs-ties-to-outside-world



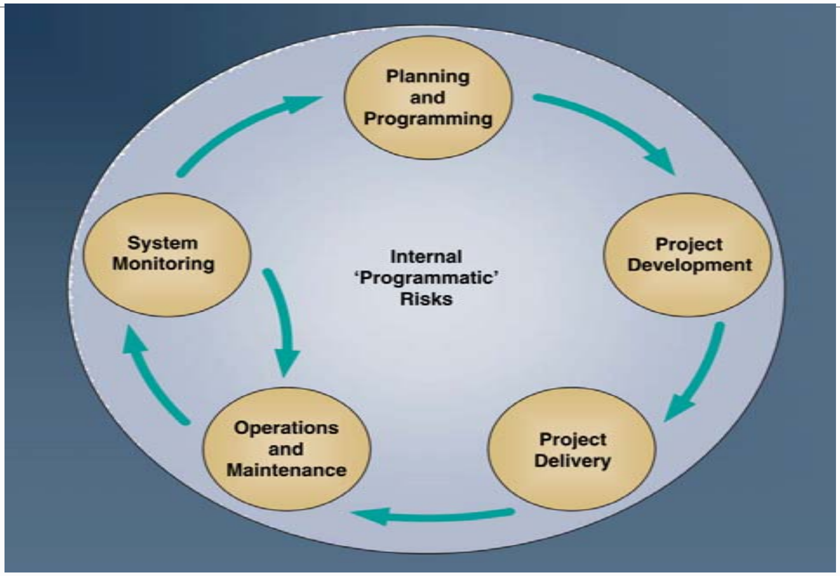
Structural failure of bridge resulting from Structural Defects

*http://marylandconstructiondefectattorney.com/structural-defects/

- Geometric Changes cause deformation during service life and eventually structural collapse
- Inability to detect the impact of a geometric change may miss early detections of pending structural integrity and stability issues

Bridge Management System (BMS) Techniques for Asset Management

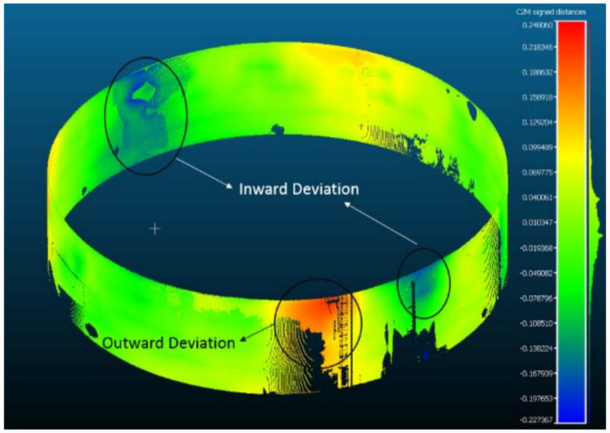
Existing transportation agency risk environment

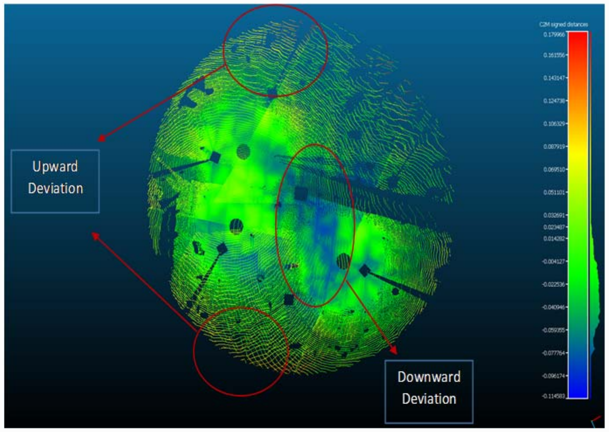


C.W. Jenks, C.F. Jencks, A.C. Lemer, E.P. Delaney, M.B. Hagood, **An Asset-Management Framework for the Interstate Highway System**, 2009

- Transportation Research Board (TRB): Asset management (AM) framework
- Strategic maintaining, managing, and upgrading physical assets

Sensor Data-driven
Bridge Geometric Change Monitoring
3D Laser Scanning Technology





Deformation of the steel water tank using 3D point cloud data

("Red" indicates positive deviation; "Blue" indicates negative deviation)

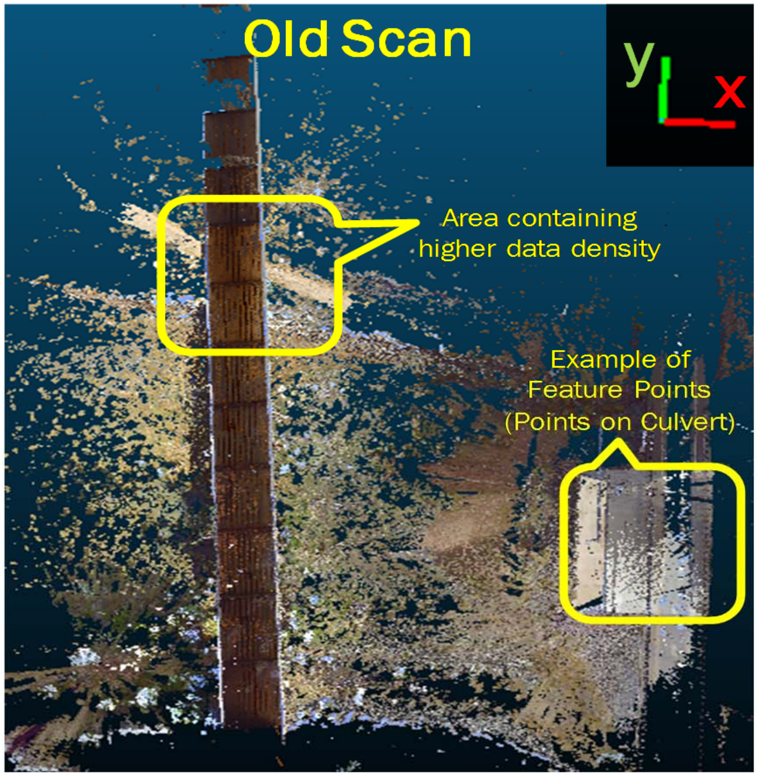
*Help track **geometric changes** by conducting **multiple data collection activities** of a bridge structure at **different times** and help in constantly **updating the condition of the bridge***

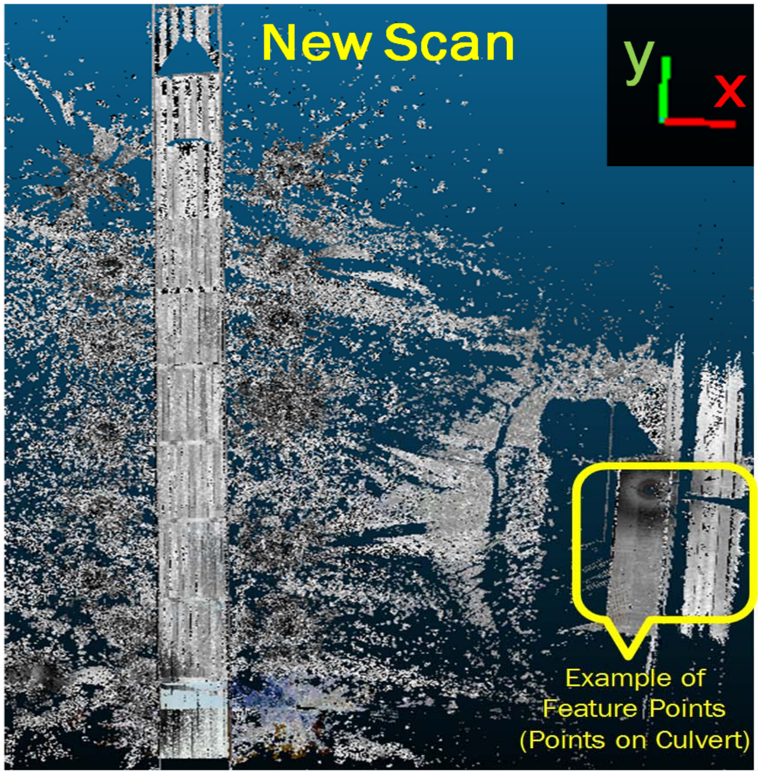
- Generates **millions of 3D points** per seconds with mm-level accuracy
- Capture **3D geometries** of infrastructures

Sensor Data-driven
Bridge Geometric Change Monitoring
3D Laser Scanning Technology

- Multiple data collection activities for conducting detailed geometric change assessment
- Challenge: **How do you register the above two data sets** ?
  - Improper registration causes irregular detection of geometric changes
  - Accurate registration plays key role for detecting geometric changes

Major Practical Challenge





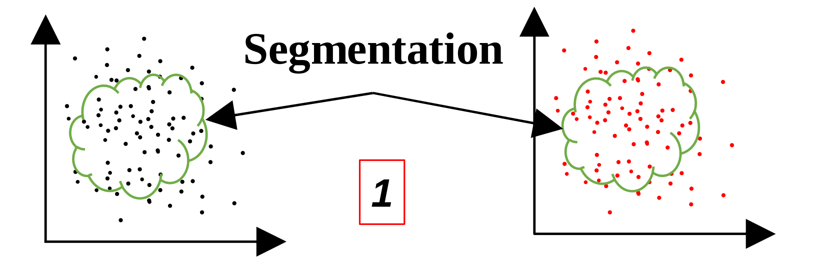
Current Registration Methods use Manual Feature Point Selection and ICP Algorithms

Do not automatically ignore changed parts causing errors in registration

- Feature points in a 3D laser scanning include points on both the surrounding (**environment feature points**) such signs on bridges/roads, railings on the roads, mile markers, etc. and the bridge structure (**bridge feature points**)
- **Iterative Closest-point (ICP)** fails in situation having mixed density scans

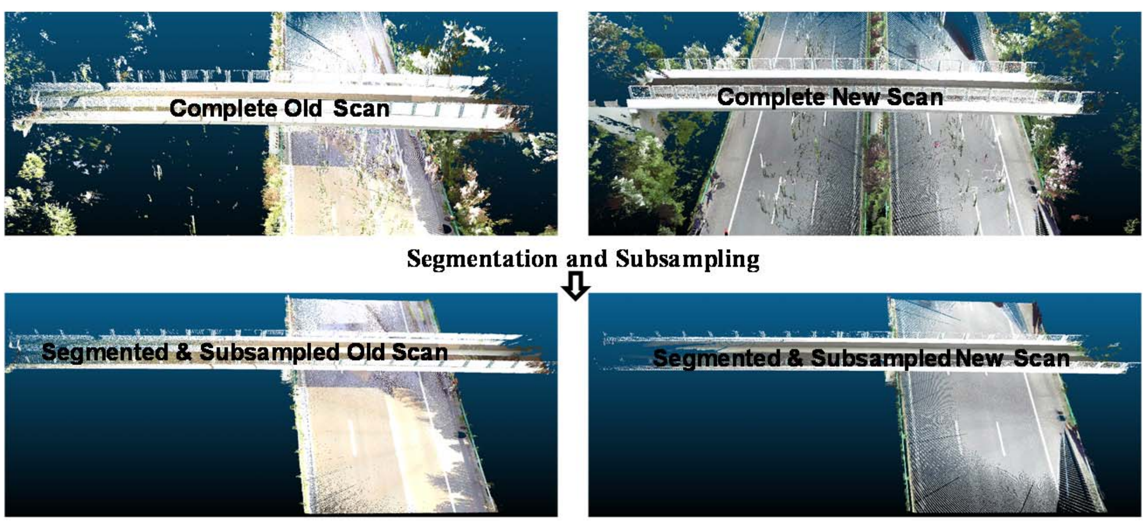
Robust Registration Approach

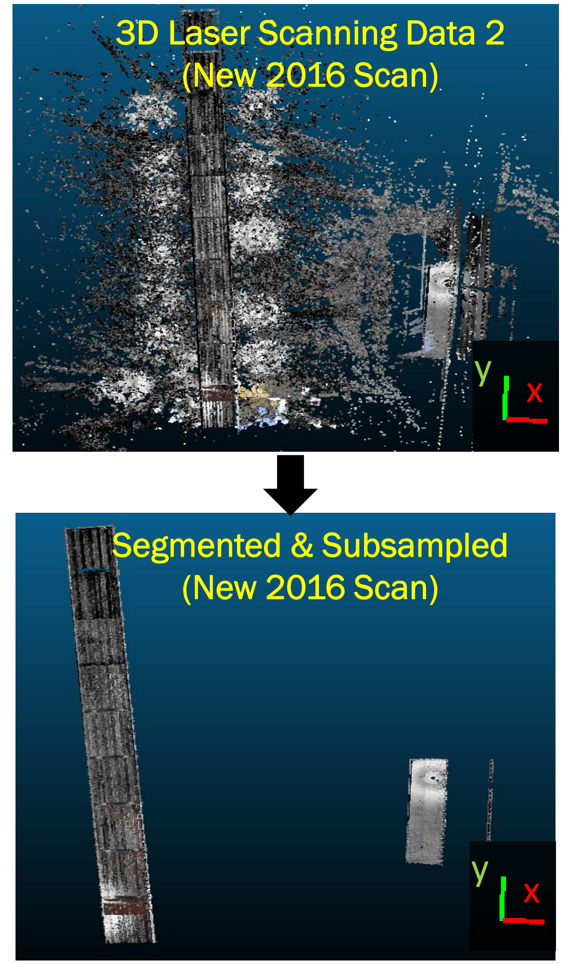
Old Scan Data **New Scan Data**



Two laser scanning data sets collected at different times of a structure (structure + envi)

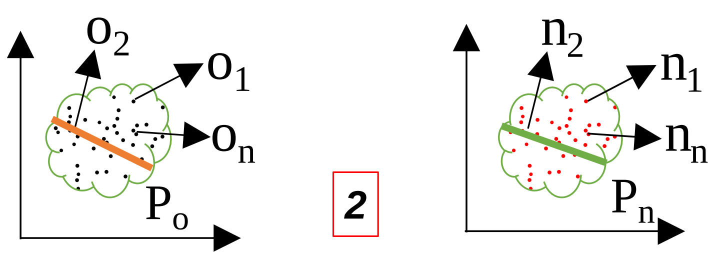
Segmentation maintains *similar environment features* between scans and Subsampling *maintains equal scan densities*





Robust Registration Approach

Robust Plane Fitting

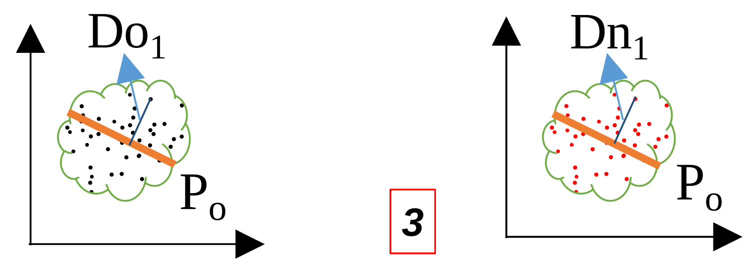


Old Scan Points (o_1 **…..** o_n)
New Scan Points (n_1 **…..** n_n)
Robust Plane Fitting using PCA (P_o & P_n)

Output of plane fitting process is the **center of the plane** and the **orthogonal distances** between the fitted plane and all the points

Select Points using Orthogonal Distance

Distance btw Planes = $\mathbf{D_{on}}$



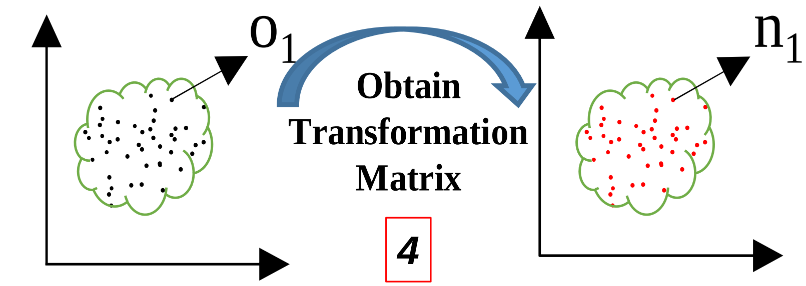
Plane ($\mathbf{P_O}$**) between both data sets and Identify** $\mathbf{Do_1}$ **&** $\mathbf{Dn_1}$ **(Orthogonal Dist.)**

If $\mathbf{Do_1 - Dn_1 < D_{on}}$
Select Points ($\mathbf{o_1}$ **&** $\mathbf{n_1}$**)**

- Associate every point in the old scan to each point in the new scan using the **nearest neighbor approach**
- **Automatically** select points having no change in orthogonal distance

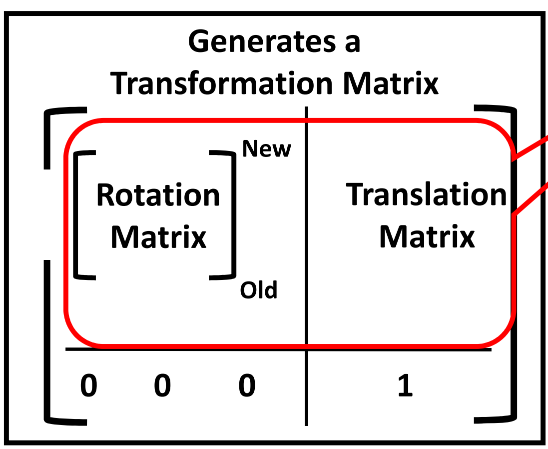
Robust Registration Approach

For all Selected Points



Apply the obtained **transformation matrix** over the entire old & new scan data

Ignore changed points and obtain transformation between selected points Apply the obtained transformation matrix over the entire old & new scan data



A transformation matrix

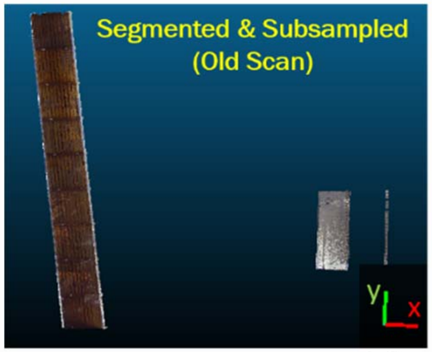
Consists of **translation parameters** that consist of *displacement along x, y, and z coordinates* and **rotation parameters** that consists of *rotation along α (rotation around the x-axis), β (rotation around the y-axis), and γ (rotation around the z-axis)* that helps to register two 3D laser scanning data sets

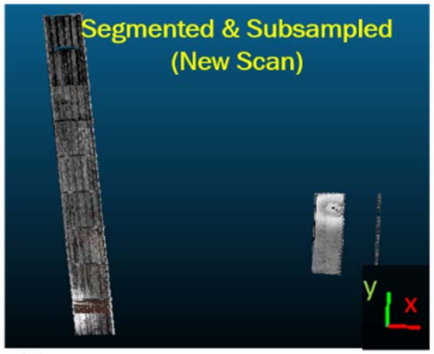
Advantages of using Robust Registration Approach

- Robust registration **accurately aligns two data sets** of a structure containing geometric changes
- **Automatic approach** for detecting geometric changes between two sets of 3D laser scanning data collected at different times
- Accurately aligned point cloud data sets can help detect
  - **Global Deviation of Bridge** (rigid body motion of the structure)
  - **Global Deviations of Bridge Elements** (interactions between connected elements)
  - **Local Deformations of Bridge Elements** (tension, compression, bending, and torsion)

Case Study

- 2-Lane Pre-stressed Concrete girder bridge located in Mesa, Arizona over Salt River
- 3D laser scanning data of the highway pre-stressed Concrete Bridge collected in 2015 and 2016





Robust Registration

0.999	-0.0009	-0.0024	1.123
0.0009	0.999	0.0053	-2.308
0.0024	-0.0053	0.999	-0.1014
0	0	0	1

Transformation Matrix

Validation: Robust Registration

Comparison of Robust Registration vs.
Registration using Manual Feature Point Selection

- Robust registration approach is **qualitatively same** but slight **vary quantitatively** from the registration results using manual feature point selection
- Both the registration approaches output results that have the **same direction** of **translation** and the direction of **rotation** along all the coordinate axes

REGISTRATION TYPE	TRANSLATION VALUES			ROTATION VALUES		
	X	Y	Z	α	β	γ
Robust Registration Approach	1.123	-2.308	-0.1014	0.0053	0.0024	-0.0009
Registration using Manual Feature Point Selection	1.208	-2.743	-0.0812	0.0078	0.0026	-0.0001

Conclusions and Future Work

Summary

- The **robust registration** algorithm accurately registered two sets of 3D laser scanning data of a bridge structure collected at different times for reliably detecting **rigid body motions** of the entire bridge and **global deviations** of bridge elements
- Does not require any **manual intervention** or the **tedious** process of manually selecting unchanged points

Future Work

- Plans to develop a **3D imagery data-driven** bridge deterioration monitoring and decision making framework
- Evaluates the **health of a bridge structure** becoming an integrated part of the bridge management system for **conducting reliable risk asset management**

Thank You
Questions?

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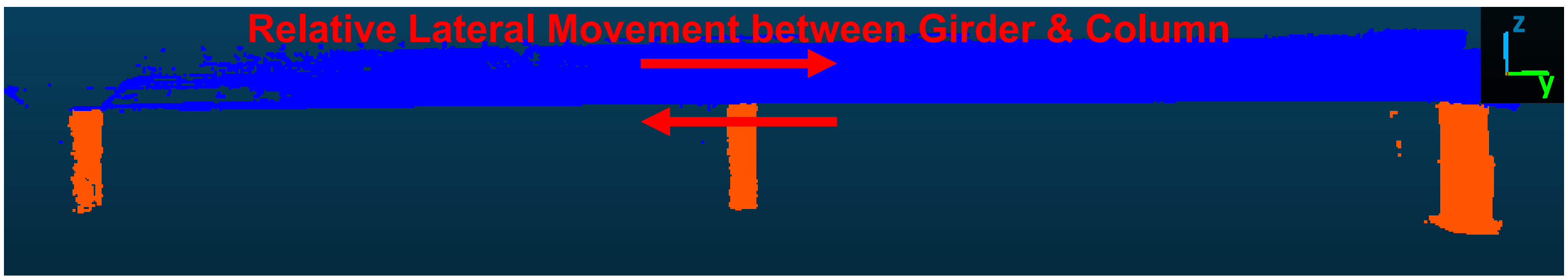
G1


Clockwise
Rotation
Front view of the bridge
Along -ve Y
Along +ve Z
Old Scan
Side view
Along +ve X
z
y
x

G2


Relative Lateral Movement between Girder & Column
z
y

L


Torsion of the Girder
Inward
Outward
z
y

Iterative Robust Registration: Iterative selection of unchanged points

REGISTRATION TYPE	TRANSLATION VALUES			ROTATION VALUES		
	X	Y	Z	α	β	γ
Robust Registration Approach	1.123	-2.308	-0.1014	0.0053	0.0024	-0.0009
1st Iteration of Robust Registration	1.221	-2.74	-0.0347	0.0064	0.0028	-0.00006
2nd Iteration of Robust Registration	1.262	-2.716	-0.3046	0.0059	0.0063	-0.0032