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?

**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.

*Fatigue Crack*  
*Irregular Settlement*

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*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?

- 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

Damaged Pfeiffer Canyon Bridge
https://www.sott.net/article/343726-Bridge-damage-severs-Big-Sur-s-ties-to-outside-world

Structural failure of bridge resulting from Structural Defects
*http://marylandconstructiondefectattorney.com/structural-defects/*
Bridge Management System (BMS) Techniques for Asset Management

Existing transportation agency risk environment

- 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

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.

Deformation of the steel water tank using 3D point cloud data
(“Red” indicates positive deviation; “Blue” indicates negative deviation)

• 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

- Feature points in a 3D laser scanning include points on both the surrounding (environment feature points) such as 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.

Current Registration Methods use Manual Feature Point Selection and ICP Algorithms.

Old Scan

New Scan

Area containing higher data density

Example of Feature Points (Points on Culvert)

Example of Feature Points (Points on Culvert)

Do not automatically ignore changed parts causing errors in registration.
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 (o₁ … oₙ)
New Scan Points (n₁ … nₙ)
Robust Plane Fitting using PCA (P₀ & Pₙ)

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 = D_{on}

Plane (P₀) between both data sets and Identify Do₁ & Dn₁ (Orthogonal Dist.)

If Do₁ - Dn₁ < D_{on}
Select Points (o₁ & n₁)

• 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

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 \( \alpha \) (rotation around the x-axis), \( \beta \) (rotation around the y-axis), and \( \gamma \) (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

Transformation Matrix

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### 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.

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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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Front view of the bridge

Clockwise Rotation
Along +ve Z
Along -ve Y

Old Scan

Relative Lateral Movement between Girder & Column

Side view Along +ve X

G1

G2

Torsion of the Girder
Inward
Outward

L
Iterative Robust Registration: Iterative selection of unchanged points

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