Cross-time registration of 3D point clouds

3D registration for cultural heritage restoration, preservation and monitoring.
Motivation and contribution
Problems identified

- Large timescale of cultural heritage applications
- No existing method specific for cross-time registration
- No existing benchmark specific for cross-time registration

Example of ground truth vs 3D registration using traditional optimization approach
Paper contributions

- Formal problem definition and framework proposal.
- Novel down-sampling method.
- Fulfilling a need of adequate benchmarking.
- Evaluation of state-of-the-art methods on performance.
Proposed methods
Cross-time registration pipeline

- Down sample
- Model segmentation
- Feature extraction
- Fine alignment
Eroded Cultural Heritage Objects dataset
Implementation
Cross-time reg pipeline

Curvature down sampling (CDS)

Find principled curvature

Down-sample by retaining $S = 1024$ points with the least curvature.

Illustration of surface deformation\(^1\).

Illustration of principled curvature on saddle surface\(^2\).

\(^1\) SIMULATING EROSION ON CULTURAL HERITAGE MONUMENTS
\(^2\) PRINCIPAL CURVATURE, WIKIPEDIA
Rigorously rotation invariant feature extraction block (RRI)

**RRI definition:**

Where $\mathcal{F}: \mathbb{R}^{N \times 3} \rightarrow \mathbb{R}^{N \times D}$ such that

$$\mathcal{F}(S) = \mathcal{F}(R(S))$$

Holds for all point set $S \in \mathbb{R}^{N \times 3}$ and rotation mapping $R \in SO(3)$.

4 features: distance, angle, sine and cosine.

Simple example of RRI transforms
Cross-time reg pipeline

**Siamese architecture of KPConv network**

Segments the point cloud

Inspired by convolution on images
  - Kernel pixels - Kernel points
  - Weighted connections – weighted points
  - Segmented image – segmented cloud

Point-to-component correspondence

KPConv on 2D points for a simpler illustration\(^1\).

\(^1\) KPConv: Flexible and Deformable Convolution for Point Clouds
Siamese architecture of KPConv network

Controlled by regularization
Further improves improvements for CrossTimeReg

Deformable KPConv illustrated on 2D points\(^1\).
Deep gaussian mixture regression model (DeepGMR)

Equivalent with DeepGMR

From association matrix to GMM parameters

Minimize KP-divergence

Aligns component centroids
Cross-time reg pipeline

Loss function

Directed Hausdorff Distance

Suitable for erosion

Minimizes:

\[ L = \sqrt{D_H + D_{MH}} \]

Backpropagated to KPConv

Where

\[ D_H : \text{maximum of the directed Hausdorff distances } D_h. \]

\[ D_{MH} : \text{average directed Harsdorf distance} \]

\[ D_h = \max_i \left( \min_j (p_i - \hat{p}_j) \right) \]
ECHO dataset creation

Sourced 3D models

- Chancay
- Lurin
- Maranga
- Nazca
- Pando
- Supe
- Jar
- Pitcher
- Bowl
- Figurine
- Basin
- Pot
- Plate
- Vase
ECHO dataset creation

Dataset augmentation

Rigid transformations
  - Unrestricted random rotation
  - Restricted random translation
Surface degradation

Simplified weather model

Simulated by diffusion equation:

\[ \hat{P} = P + \delta n dt, \]

Where \( n \) and \( \delta \) consist of all normal vectors and surface alteration respectively of each corresponding point in \( P \).

\( \delta_i > 0 \Rightarrow \) surface deposition

\( \delta < 0 \Rightarrow \) surface recession
Performance evaluation
Metrics

Error (R) – Absolute rotation difference (LB)
Error (t) – Absolute translation difference (LB)
RMSE – Error from prediction vs target transform (LB)
RMSD – Surface similarities between GT and pred (LB)
Recall (%) – portion of tests with RMSE above 0.2 (HB)
### Synthetic data without erosion

<table>
<thead>
<tr>
<th>Method</th>
<th>Error(R)</th>
<th>Error(t)</th>
<th>RMSE</th>
<th>Recall (%)</th>
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Erosion over time
Efficiency
Qualitative assessment
Conclusion
Achievements

Computationally efficient and stable method for Cross-time reg
Outperforming state of the art methods on cross-time reg
Publicly available dataset for further experimentation
Future work

Optimalisation of subsampling step
Framework integration
Mesh folding not addressed
Non-uniform, more realistic erosion model
Sources

Videos by The Instagrapher/Adrien JACTA – Pexels.com


