Window-Based Range Flow with an Isometry Constraint

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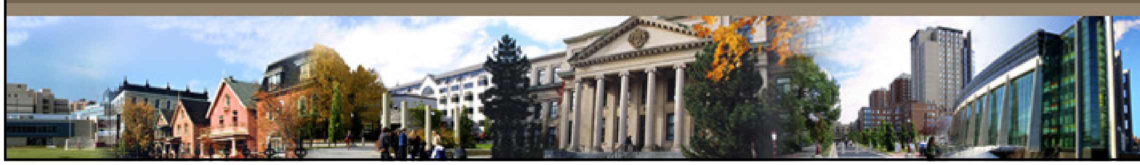
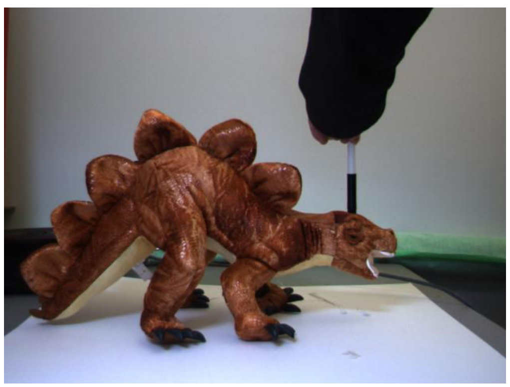
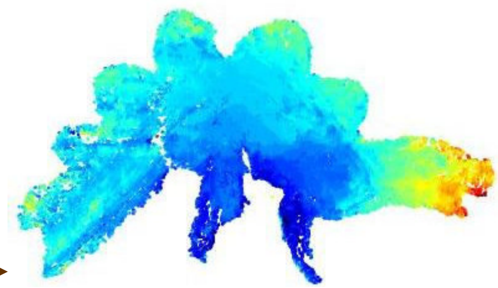
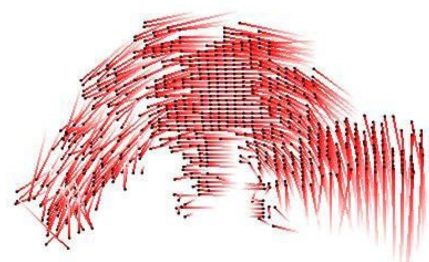


Goal

- **Modelling human-object interactions from observations.**
  - Obtain an interaction model by estimating a relationship between forces and surface deformation in unconstrained settings.







Approach

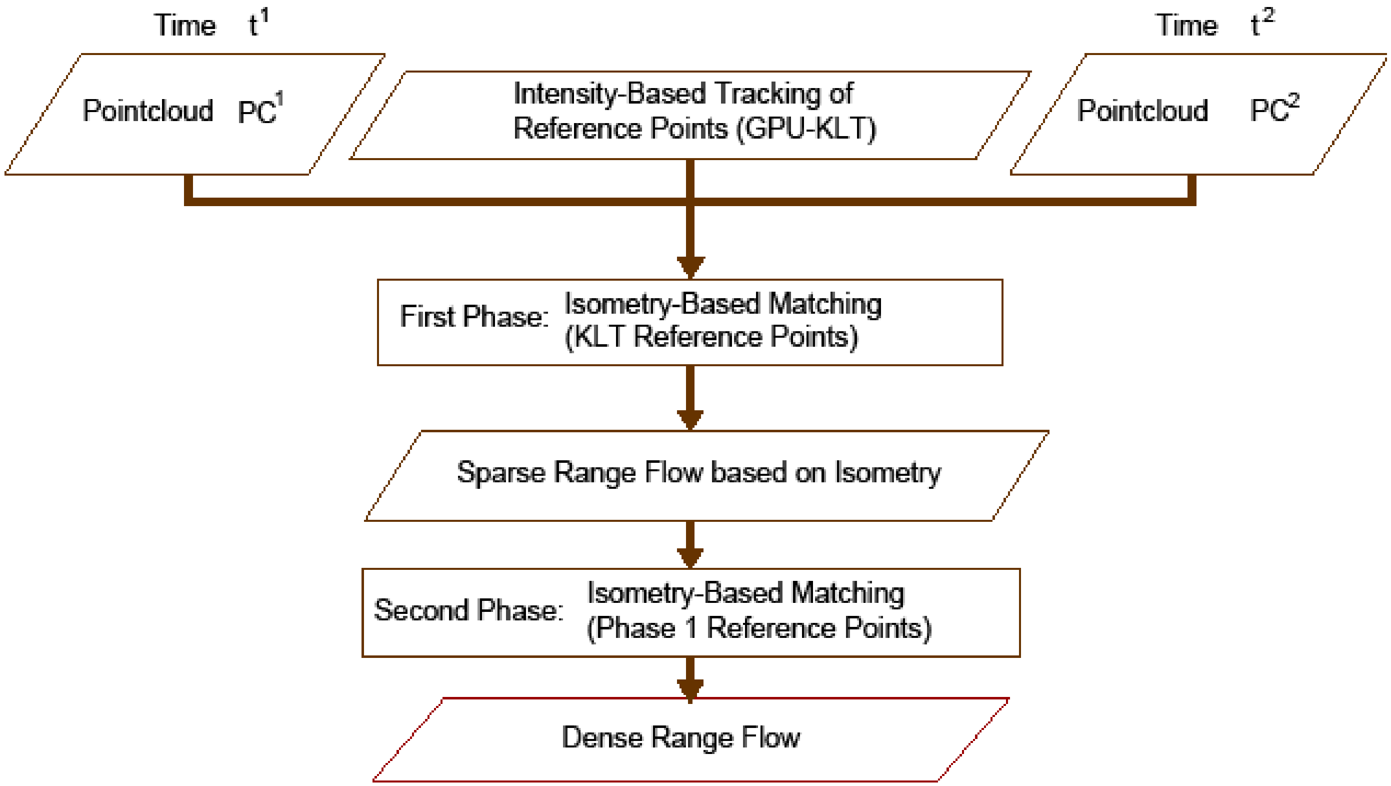
- **Employ isometry constraint in a local flow method**
- **Motivation:**
  - Optical flow for intensity and range images work well for small flow
    - E.g., Mequon sequence of [Baker et al.] has a maximal flow of 10 pixels.
    - Scene Flow [Vedula et al. '05], Range Flow [Spies et al. 02] [Schuchert et al. '08]
  - Recent deformable registration methods, e.g., [Pritchard and Heidrich '03, Starck and Hilton '07, Bradley et al. '08, Ahmed et al. 08, Tevs et al. '09, Li et al. '09] work well for large scale-motion between shapes
    - Often-based on assumption of isometric deformations
    - Not local flow methods

Contributions

- We propose a novel window-based matching technique for range flow based on isometric surface deformation.
- We analyze the degradation of the isometry constraint for surfaces which deform non-isometric and in the presence of topological noise.
- We apply our technique on noisy range data obtained with a commercial binocular stereo system.

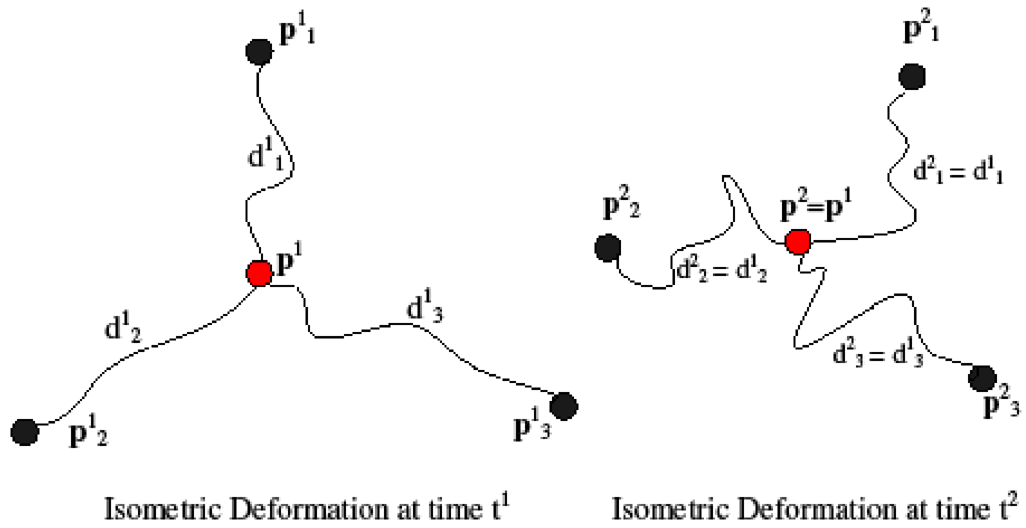
Point Grey's Bumblebee 2

Our Framework for Range Flow Estimation



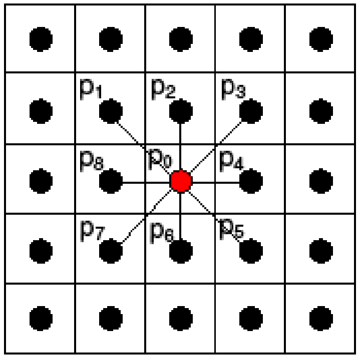
Isometry Constraint

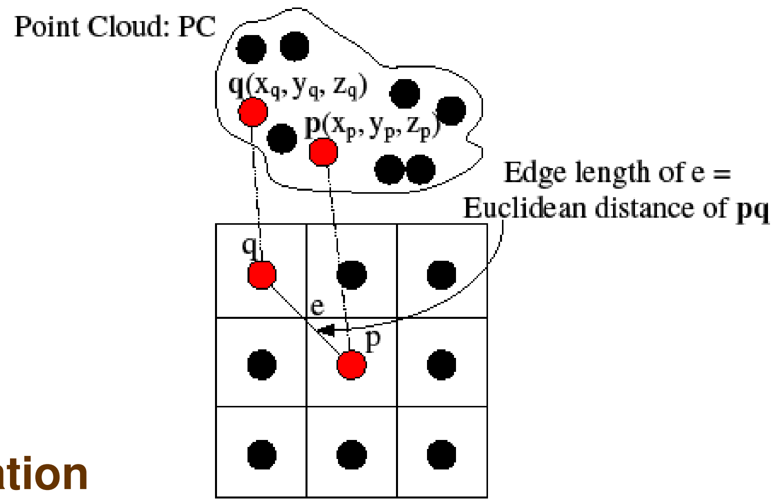
- **Tracking a surface point through different pointclouds based on the assumption that the geodesic distance between two surface points remains the same**
  – Applicable to human skin, most cloth material, etc.



Geodesic Distance Estimation

- **Embedding geodesic distance**
  - Pixel Graph embeds topological structure of the sample points on the object surface





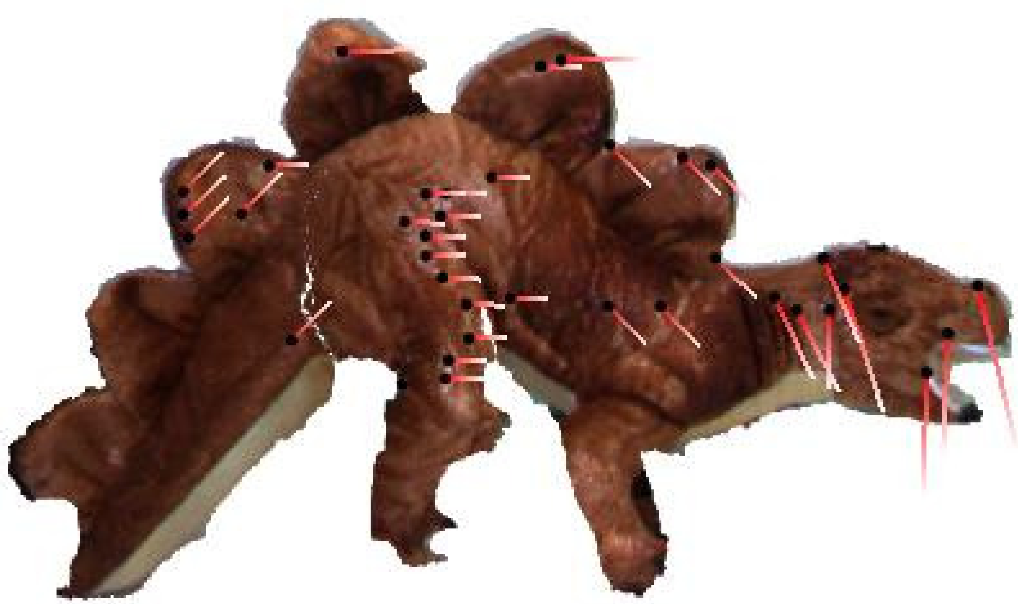
- **Geodesic Distance Approximation**
  - Approximate geodesic distance as the shortest path in the pixel graph

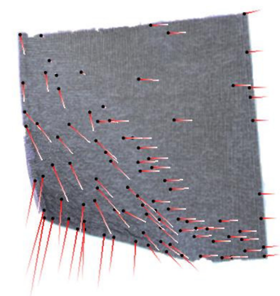
Geodesic Distance Evaluation

- **Questions**
  - Does the approximation error increase with path length?
  - Do boundary vertices in the pixel graph signal approximation error?
- **Experiment Setup**
  - Use KLT feature points
  - Evaluate the isometry constraint for each feature point based on all other feature points
  - For path length error
    - Use only paths without boundary vertices
  - Assumes KLT calculates the correct distance

KLT Reference Points

– Magnitude of the motion vectors is multiplied by 10.



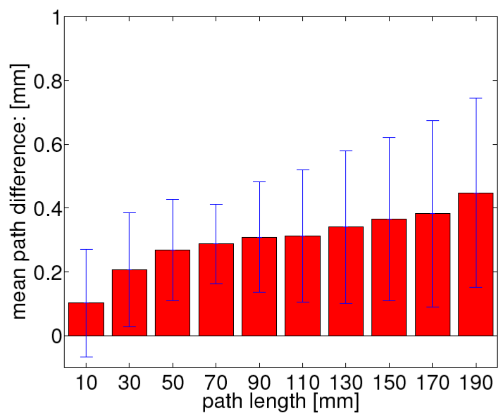


Paper

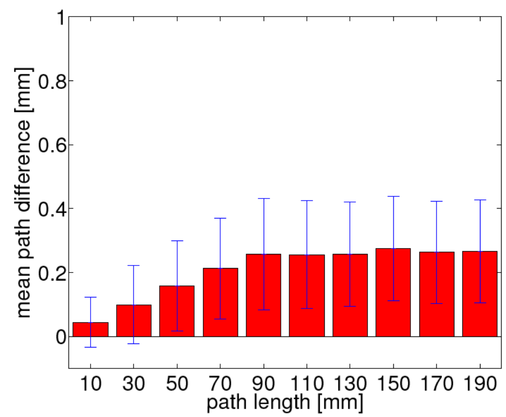
Approximation Error – Path length

– Influence of path length on the error of the geodesic approximation during deformation

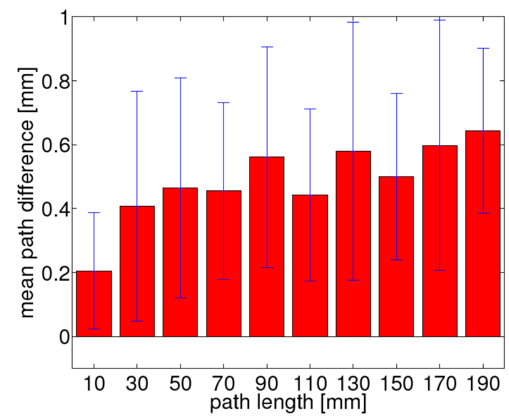
– Use only paths without boundary vertices



Paper Rotation



Paper Deformation

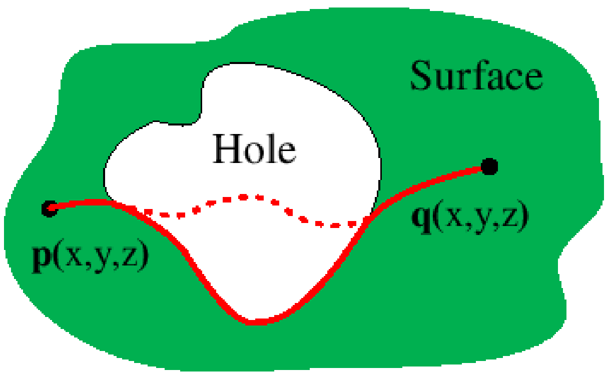


Dinosaur Deformation

→ Use path of any length

Approximation Error – Holes

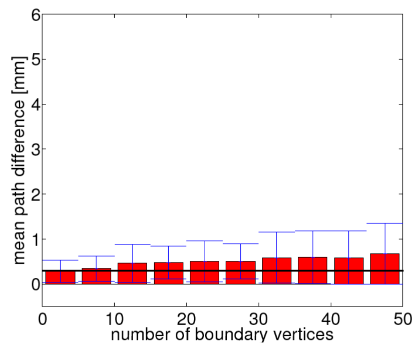
- **Boundaries in the pixel graph**
  - Filtered matches lead to holes in the stereo range images and in the pixel graph
- **Geodesic distance error**



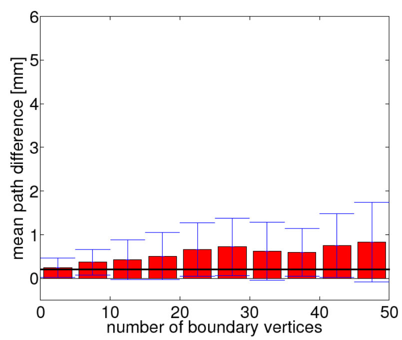
Approximation Error – Holes

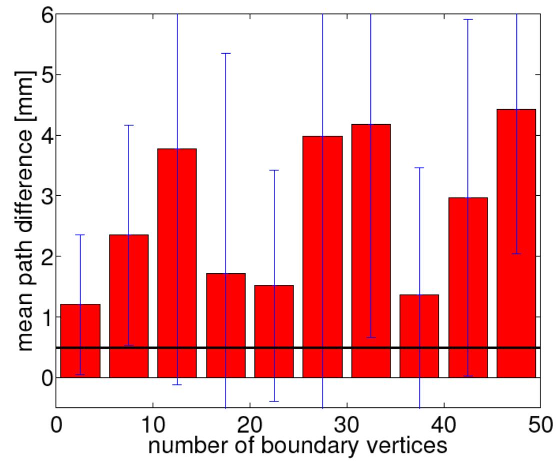
– Path with boundary vertices may have large error

Paper Rotation



Paper Deformation





Dinosaur Deformation

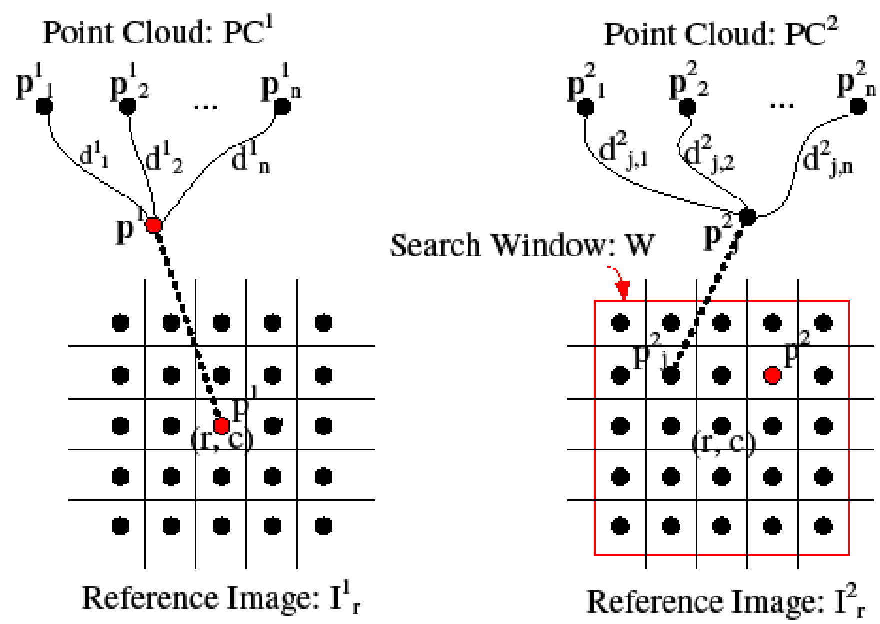
→ Not use path with boundary vertices

Two-phase Matching

- **First phase**
  - Isometry-based matching from intensity-based anchors (KLT)
- **Second phase**
  - Isometry-based matching from isometry-based anchors
- **Matching parameters**
  - Window size
  - Pixel neighborhood (in second phase only)
  - Threshold d_{max} - Maximum path length difference
  - Threshold n_{min} - Minimum number of shortest paths

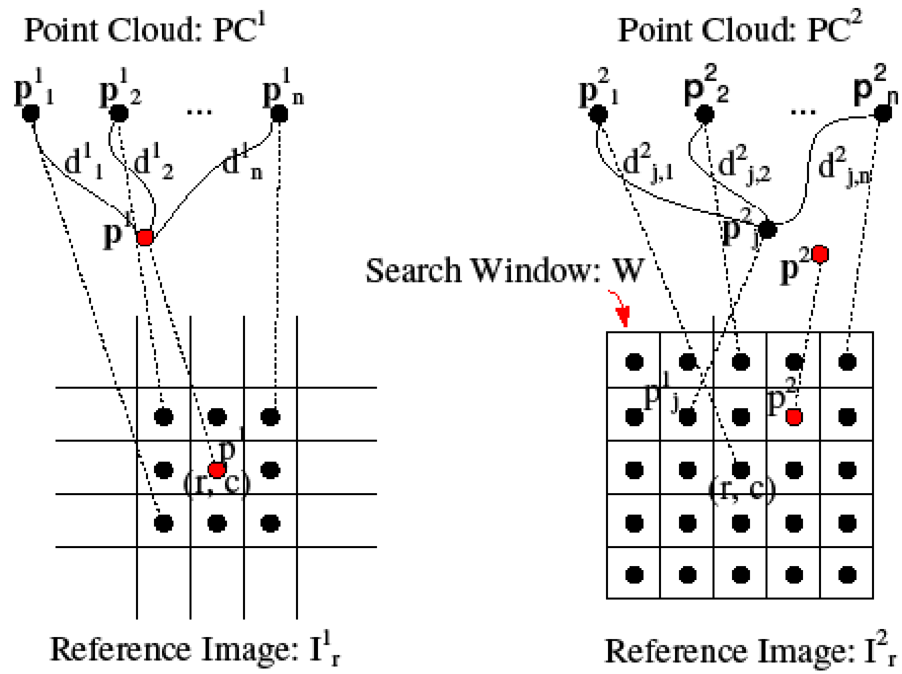
Isometry-based Matching (Phase I)

- **Matching points P^1 and P^2_j of the pointclouds PC^1 and PC^2**
  - P^1 and P^2_j project into p^1 and p^2_j in the stereo reference image
  - Store distance to KLT reference points in an image for matching



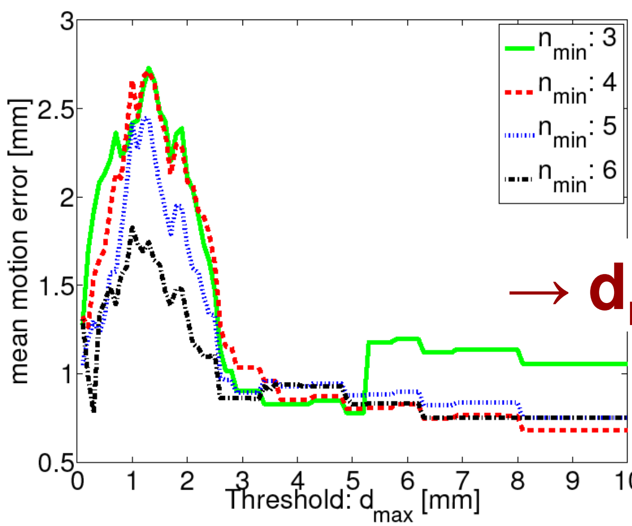
Isometry-based Matching (Phase 2)

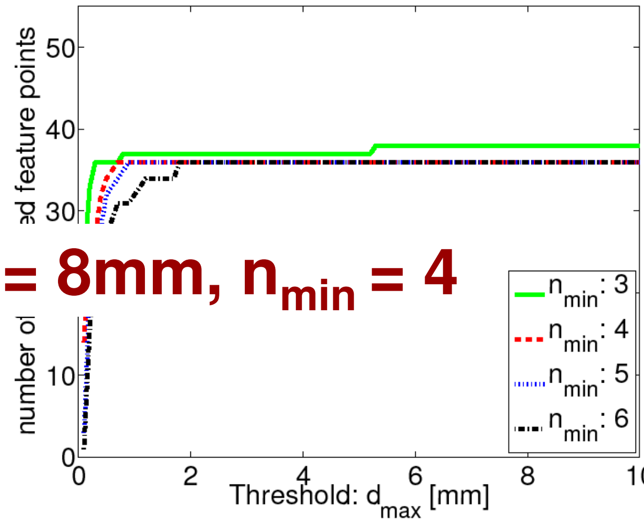
- **Matching points P^1 and P^2_j of the pointclouds PC^1 and PC^2**
  - P^1 not matched in the first phase
  - Matches of first phase as additional reference points
  - Possible to restrict references to the 8 neighborhood of a pixel



Influence of Thresholds d_{max} and n_{min}

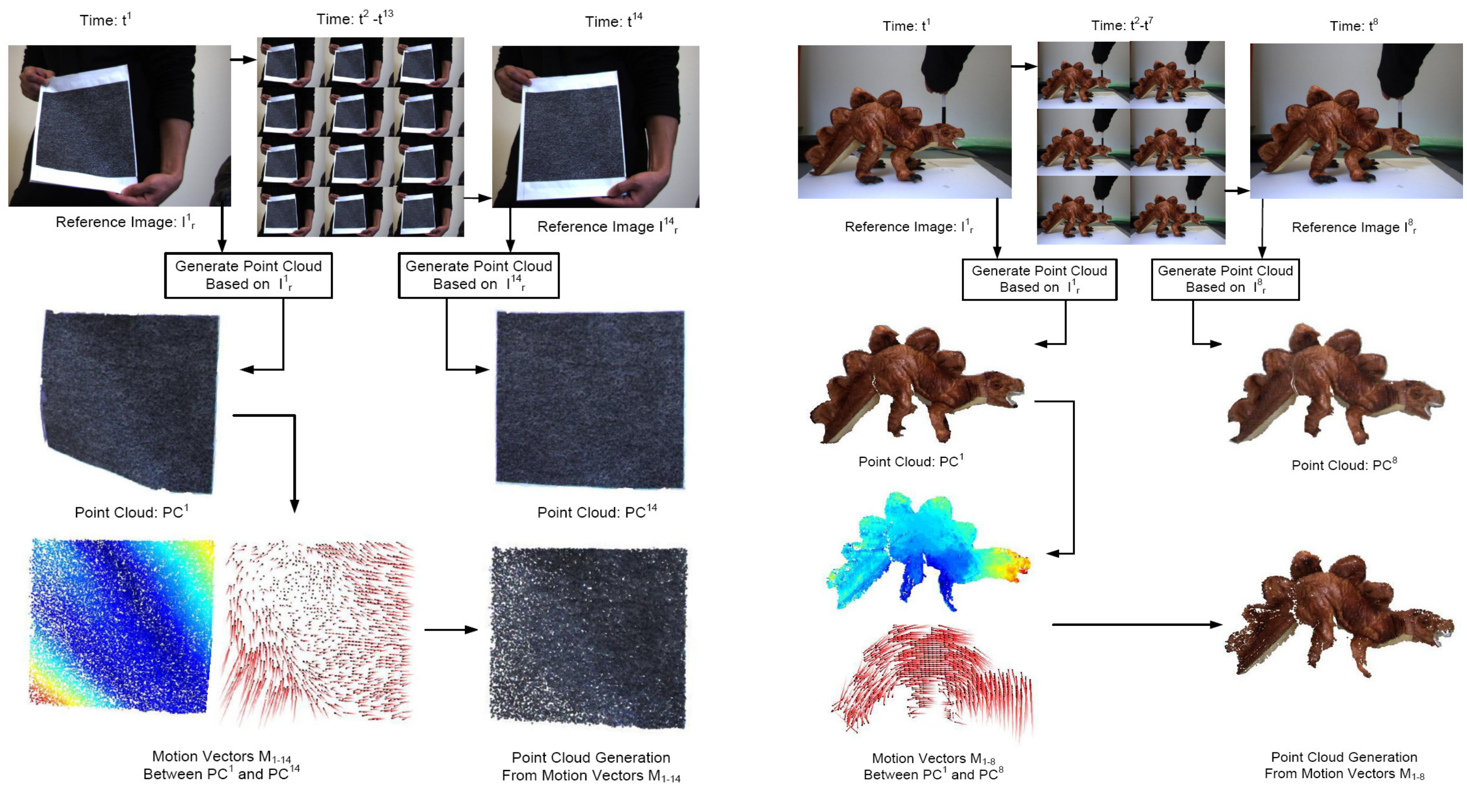
- Evaluation with KLT feature points
- Match each feature point based on other feature points as reference anchors.
- Measure motion error as 3D Euclidean distance from KLT





→ d_{max} = 8mm, n_{min} = 4

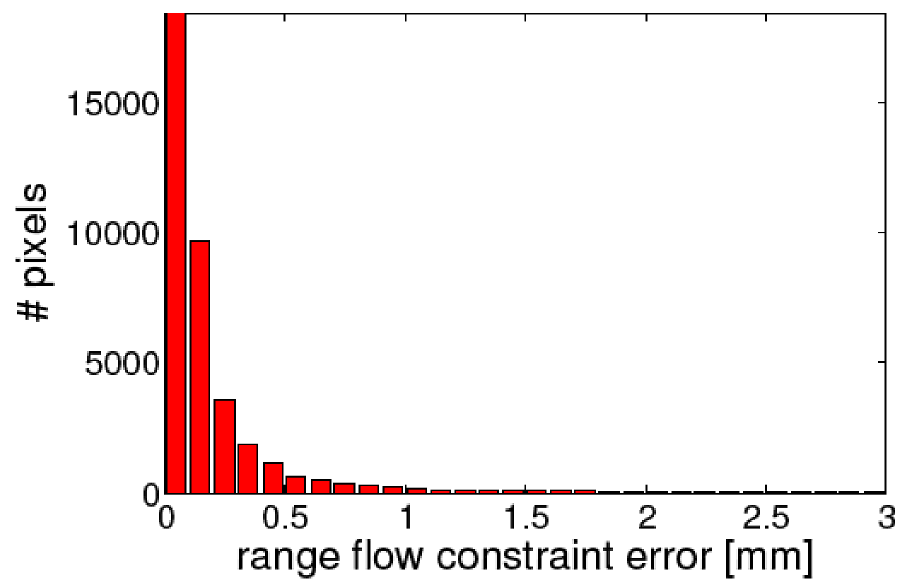
Results


Time: t^1
Time: t^2 -t^{13}
Time: t^{14}
Reference Image: I^1_r
Reference Image I^{14}_r
Generate Point Cloud Based on I^1_r
Generate Point Cloud Based on I^{14}_r
Point Cloud: PC^1
Point Cloud: PC^{14}
Motion Vectors M_{1-14} Between PC^1 and PC^{14}
Point Cloud Generation From Motion Vectors M_{1-14}
Time: t^1
Time: t^2-t^7
Time: t^8
Reference Image: I^1_r
Reference Image I^8_r
Generate Point Cloud Based on I^1_r
Generate Point Cloud Based on I^8_r
Point Cloud: PC^1
Point Cloud: PC^8
Motion Vectors M_{1-8} Between PC^1 and PC^8
Point Cloud Generation From Motion Vectors M_{1-8}

Range Flow Constraint Error

- **Evaluate range flow equation [Horn and Harris '91]**

$$z_x u + z_y v + w + z_t = 0$$



Conclusion and Future work

- **Conclusion**
  - Novel window-based matching technique for range flow based on isometry constraint.
  - Evaluated of the degradation of the isometry constraint for surfaces which deform non-isometrically and in the presence of topological noise.
  - Applied our technique to noisy range date obtained with a commercial binocular stereo system.
- **Future Work**
  - More efficient approximate closest path calculation
  - Combining the isometry constraint with range flow constraint
  - Different range data

Acknowledgements

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