Multi-View Stereo with the Profusion Camera

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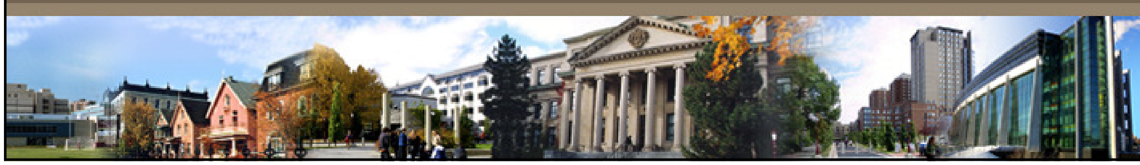

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Overview

- MVS approaches
- Profusion camera calibration
- Our Framework for the Generation of 3D Models
- Window-Based Matching
- Fusion of Volumes
- Results
- Future Work

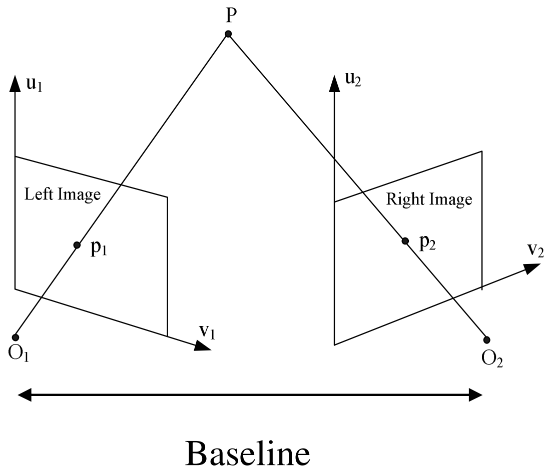
Multi-view Stereo (MVS)

- **Goal**
  - Extract three-dimensional scene structure
- **Principle**
  - Match scene structure between many simultaneous images from calibrated cameras
  - Extension of two-view stereo; epipolar constraint between many camera pairs
  - 3D reconstruction based on triangulation

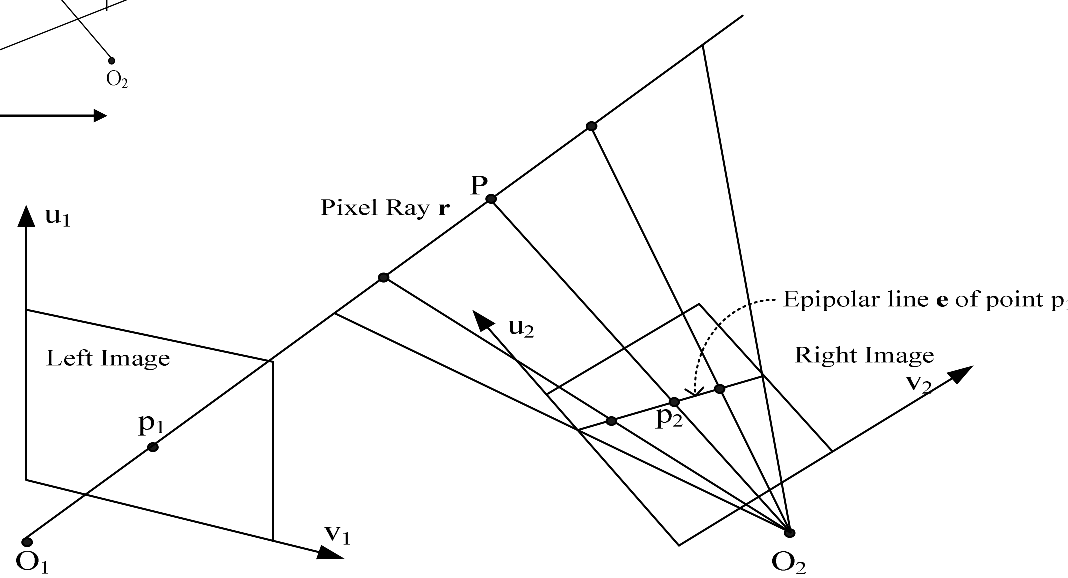
Point Grey Bumnblebee 2

View Plus/Point Grey ProFUSION 25

Triangulation and Epipolar Constraint



Same as binocular stereo but many image pairs



Basic MVS Approaches – Disparity score combination

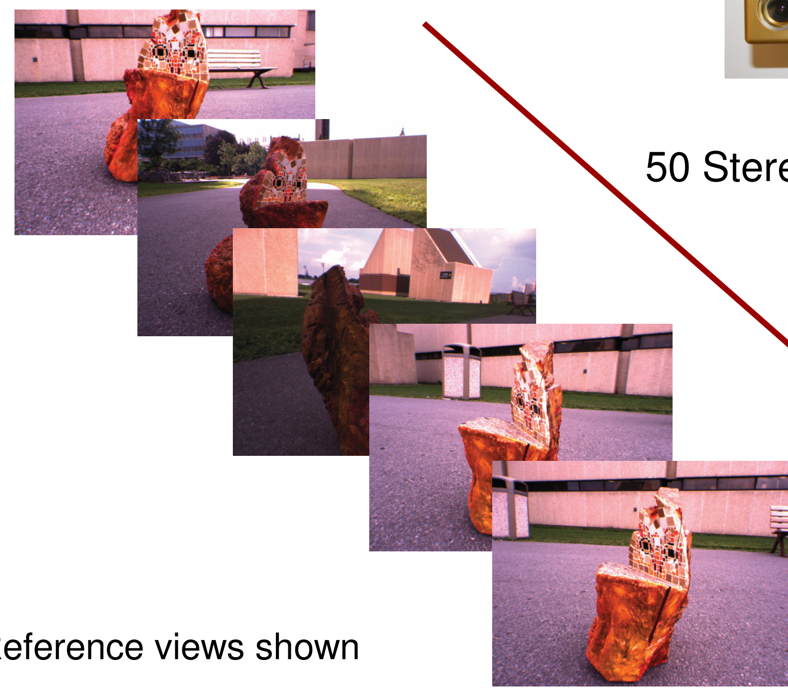
- **CMU video-rate stereo machine [Kanade et al. '95]**
  1. Pick reference view
  2. Calculate disparity scores with a window-based method to other views
  3. Sum the scaled disparity scores
- **Difficulties:**
  - Rectification not possible for general view configurations
  - Visibility changes not accounted for
  - Finds only a depth map (multi-baseline stereo)
    - but could work for the Profusion

Basic MVS Approaches – Merging depth maps

- **Multi-view stereo revisited [Goesele et al. 06]**
  - Calculate stereo between close image pairs
  - Merge depth maps similar to range scans in 3D modelling
- **Difficulties**
  - Binocular stereo is noisy
  - Filtering out noisy matches results in sparse depth maps
  - Noisy and/or sparse depth maps are hard to register and merge

Example: Merging Multiple Stereo Depth Map

- **Bumblebee reference images**



50 Stereo Pairs

3D Model

Reference views shown

Registration
[Byczkowski & Lang 08]

Simple MVS Approaches – Volumetric Reconstruction

- **Plane sweeping [Collins 96] or Octrees [Szeliski 93] or Voxel coloring [Seitz & Dyer 97]**
  - Determine scene volume
  - Split scene volume into voxels
  - Determine occupancy of each voxel based on photo-consistency
- **Difficulties**
  - Plane sweeping requires multiple passes for general camera configuration
  - Computationally expensive (use hierarchical approach)

MVS Algorithms [Seitz et al. '06]

- **Taxonomy**
  - Scene representation
  - Photo-consistency measure
  - Visibility model
  - Shape prior
  - Reconstruction algorithms
    - Merging of depth maps
    - Volumetric MVS algorithm
    - Surface evolution
    - Surface growing
  - Initialization requirements
- **http://vision.middlebury.edu/mview lists currently 49 different methods**

Advanced MVS Approaches

- **Surface Evolution**
  - Minimizing an error function to refine surface
    - Visual hull, e.g., [Laurentini 94], [Matusik et al. 00]
    - Space Carving [Kutulakos & Seitz 98]
    - Minimize difference between images and model reprojection, e.g., [Faugeras & Keriven 98], [Pons et al. 03]
- **Surface growing**
  - Seed surface with a few matches (e.g., with feature matching) and refine
    - E.g., [Morris and Kanade 00, Manessis at al. 00]

Camera Calibration

- Initial intrinsic and extrinsic parameters generated from Camera Calibration Toolbox [Bouguet]
- Final intrinsic and extrinsic parameters generated by using Sparse Bundle Adjustment (SBA) [Lourakis and Argyros 09]

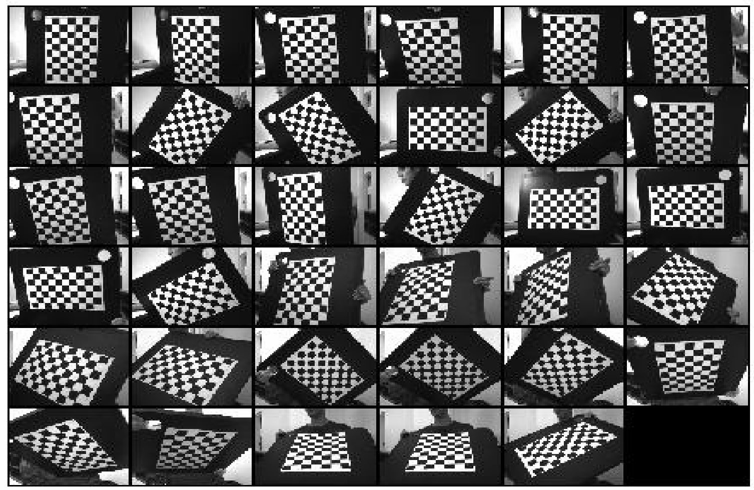
$$\min_{a_j, b_i} \sum_{i=1}^{n} \sum_{j=1}^{m} v_{ij} d(Q(a_j, b_i), X_{ij})^2$$

$Q(a_j,b_i)$ is the predicted projection of point i in camera j. X_{ij} is the projection of point i in camera j. d(X,Y) is the Euclidean distance between pixel X and Y.

- After using the SBA optimization: the average projection error of 35,100 projection decreases from **3.78 to 0.1844 pixels**

Camera Calibration Images

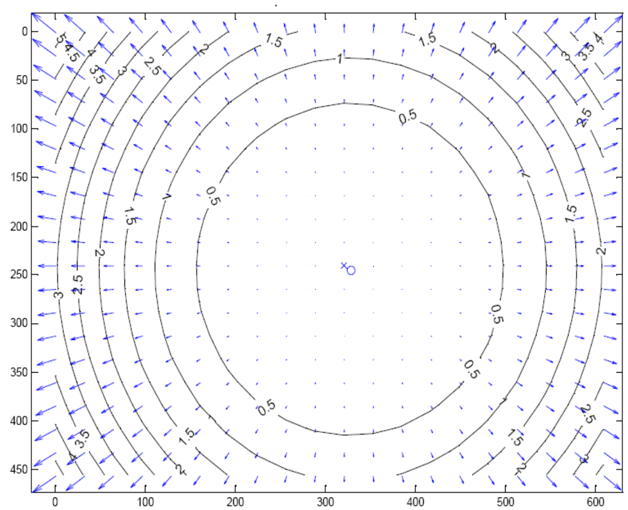
– Use a checkerboard grid pattern as known scene structure



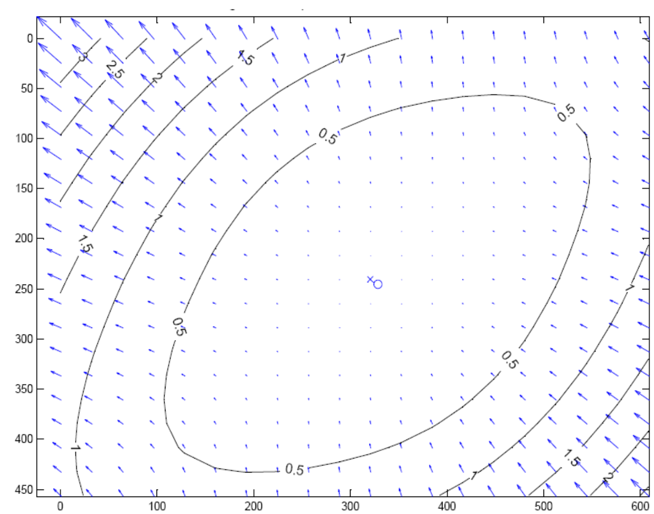
– Result: N intrinsic camera parameters and N motion estimation
– Use bundle adjustment to find a consistent calibration

Distortion Removal [Bouguet]

- Calibration toolbox uses Brown's [66] model
  - radial distortion: misalignment of spherical lens
  - tangential distortion: imperfect centering of camera lens



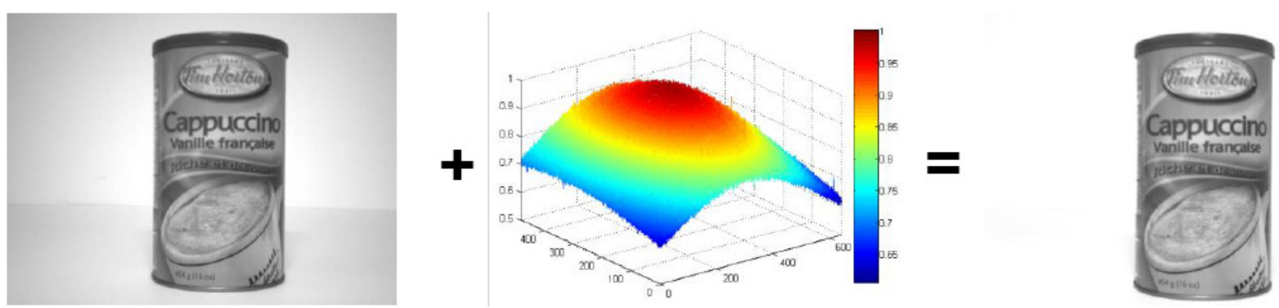
Radial distortion



Tangential distortion

Vignetting Removal

- Micro lenses of the ProFusion show pronounced vignetting
- Vignetting results in radial reduction of brightness
- Remove Vignetting with method by Fanaswala [2009]



Background Removal

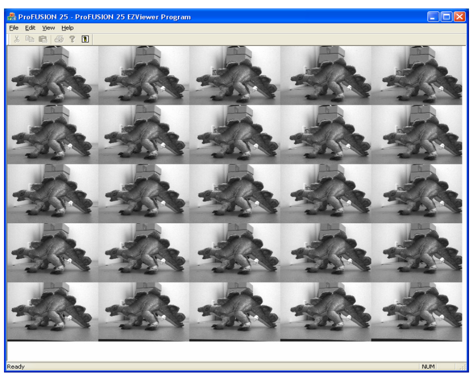
- Use uniform white background with *ambient* lighting
- Simple threshold for window difference calculated with the sum of absolute differences (SAD)

Background

Stereo Image

Background removed

Our 3D Reconstruction Framework



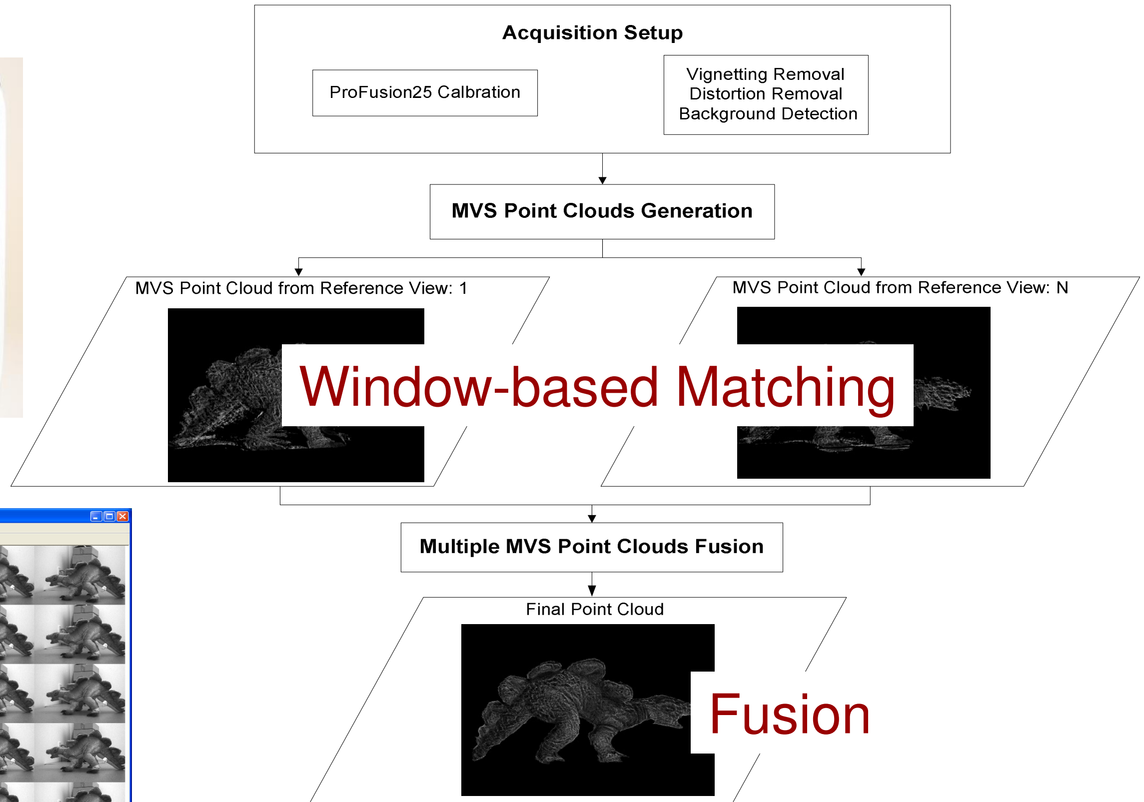
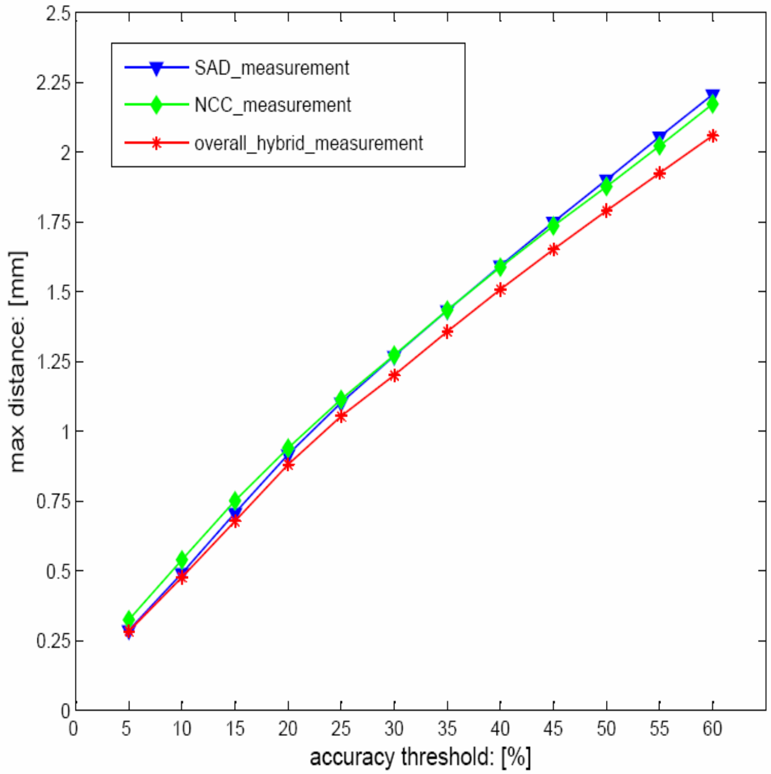
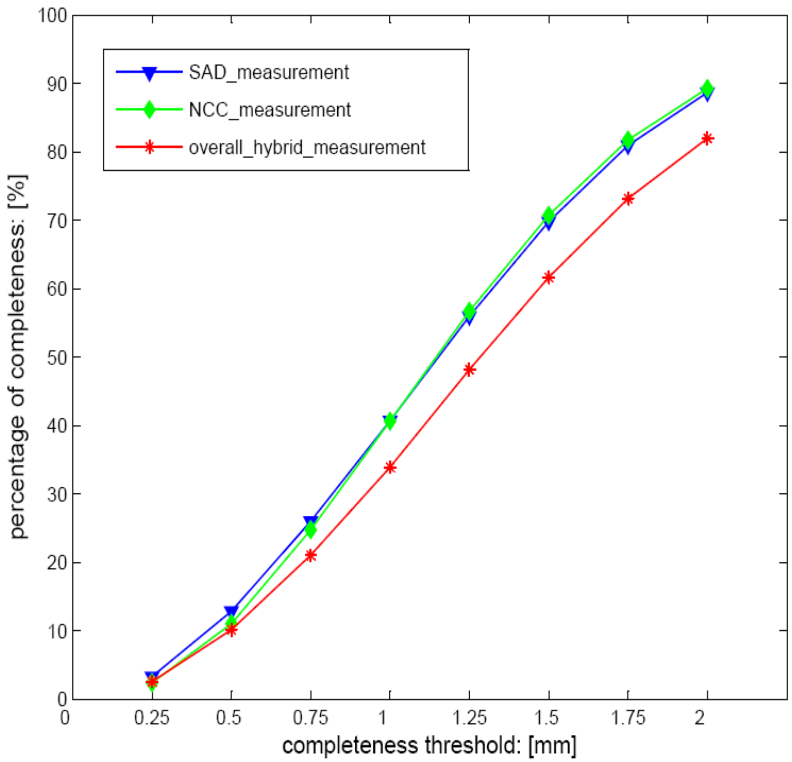


Photo-Consistency: Window-based Matching

- Intensity difference measures (SSD or SAD)
- Intensity distribution difference measures (NCC)
- Weaknesses (see also [Fua 93] for an evaluation)
  - SAD is sensitive to radiometric gain and bias
  - NCC fails for symmetrical color distribution, e.g. matching black and white windows
- Can use hybrid matching method

Matching Method Comparison

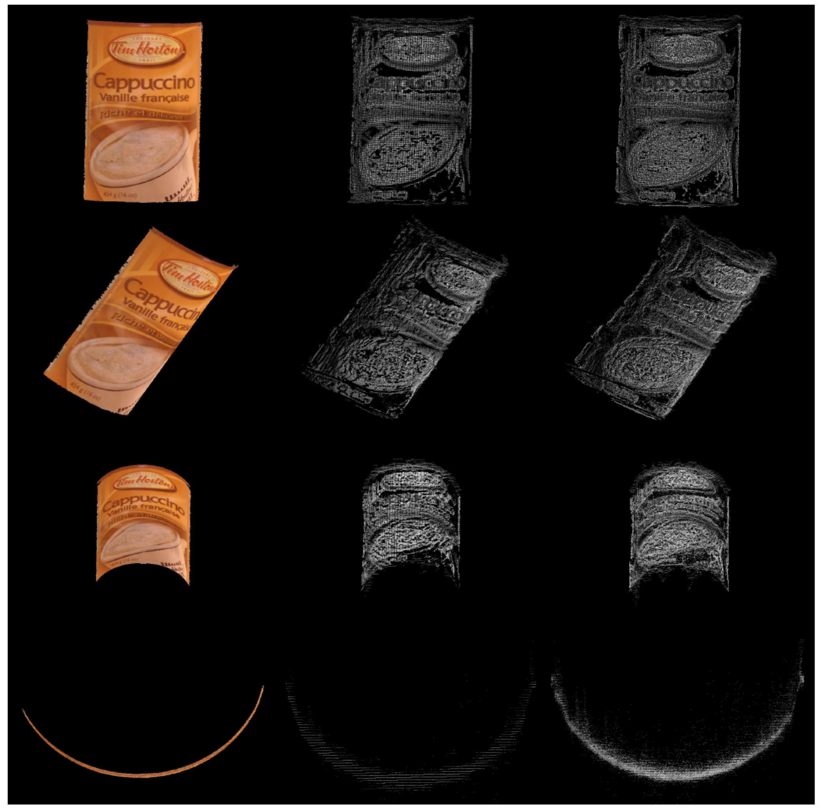




The Advantage of Fusion

From left to right

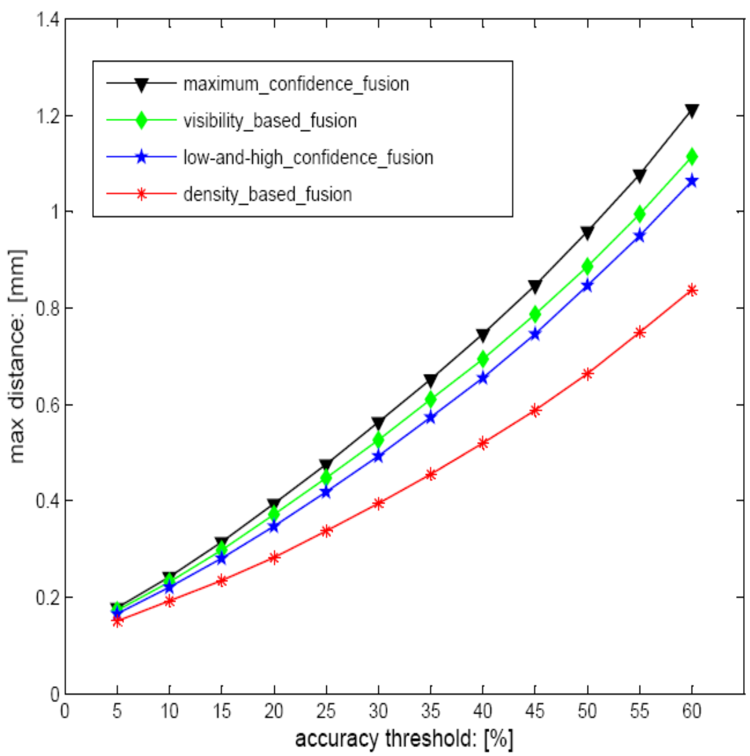
- 3D scanner (left column)
- MVS reconstruction without fusion (center column)
- MVS reconstruction with fusion (right column)

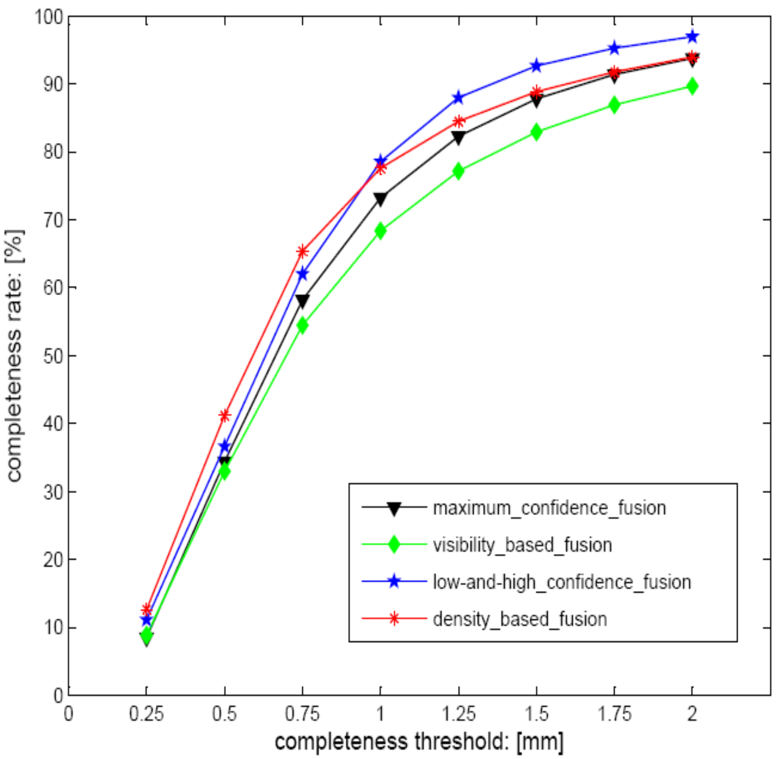


Evaluation of Fusion Strategies

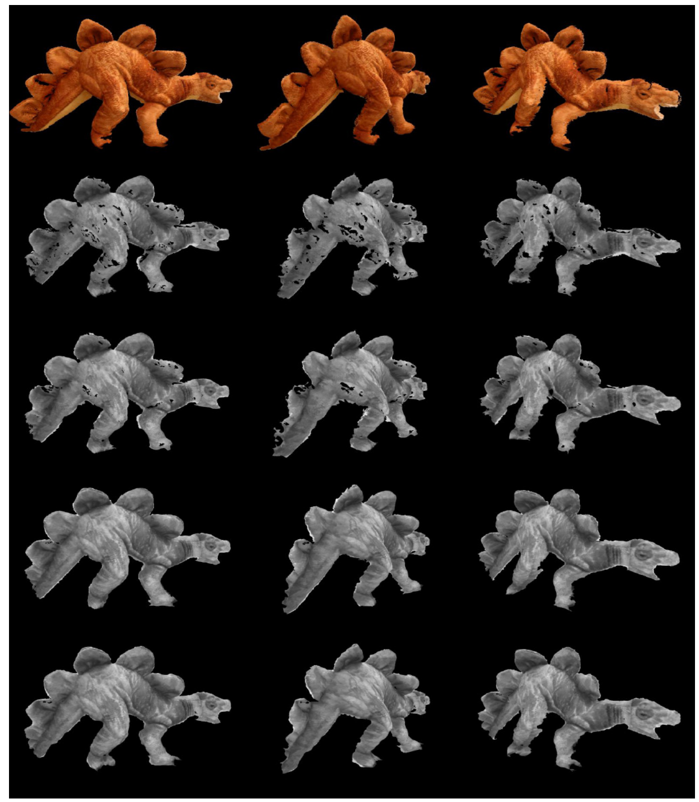
- **Two new variants:**
  - Low-and-high confidence fusion
  - Density-based fusion
- **Two additional fusion strategies as references**
  - Maximum confidence fusion
    - Similar to the low and high confidence fusion. The only difference is it only records the candidate with highest confidence value in the MVS pointcloud generation.
  - Visibility-based fusion [Merrell et al. 07]
    - It fuses the multiple MVS pointclouds by minimizing violations of visibility

Fusion strategies comparison





Fusion strategy Comparison



Conclusion and Future work

- **Conclusion**
  - A 3D Reconstruction Framework with a new matching method and two fusion strategies
- **Future Work**
  - Optimize the camera calibration and 3D reconstruction together based on the bundle adjustment [Furukawa & Ponce 08]
  - Improvements in computational efficiency
  - Combining multiple viewpoints

Acknowledgements

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