CurveFusion: RGBD-based Reconstruction of 3D Thin Structures

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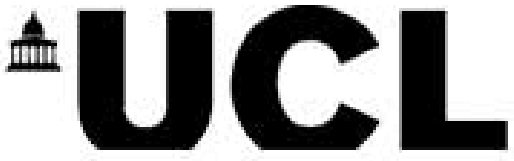


CurveFusion: RGBD-based Reconstruction of 3D Thin Structures

To reconstruct a 3D tubular model from a sequence of raw RGBD images

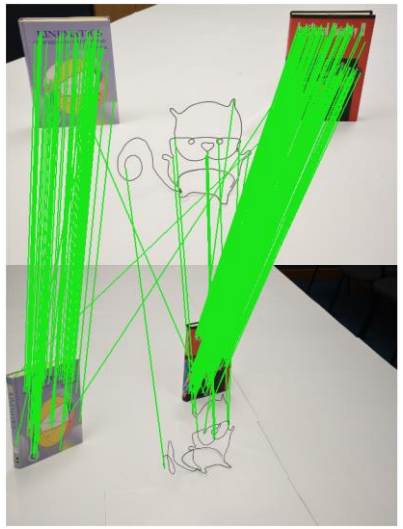
Examples of Thin Structures

Related Works: Image-based methods

Patch-based Multi-view Stereo (PMVS) [Furukawa and Ponce 2010], [Tabb 2013], Line3D++ [Hofer et al. 2016], [Usumezbas et al. 2016], [Liu et al. 2017]

1) Correspondence problem;
2) Low reconstruction quality;
3) Sensitivity to camera pose estimation; E.g. [Liu et al. 2017]
4) Special image set up. E.g. 40 calibrated cameras used in [Tabb 2013]

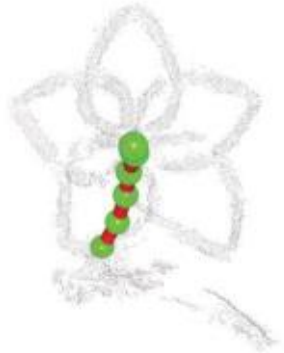
Correspondence Problem



Low Reconstruction Quality

wire object

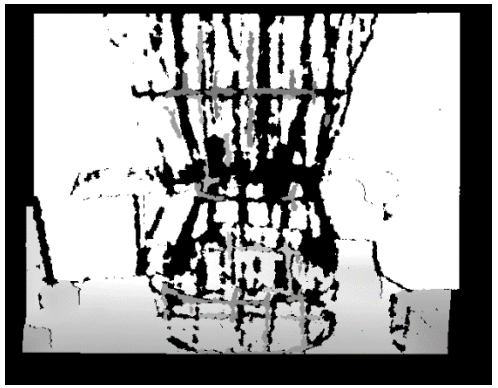
PMVS



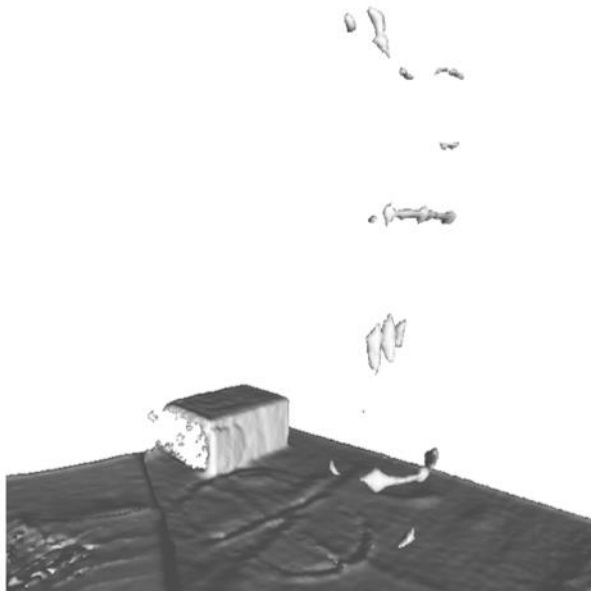
L1-Axis

Related Works: Failure of Existing Fusion Methods

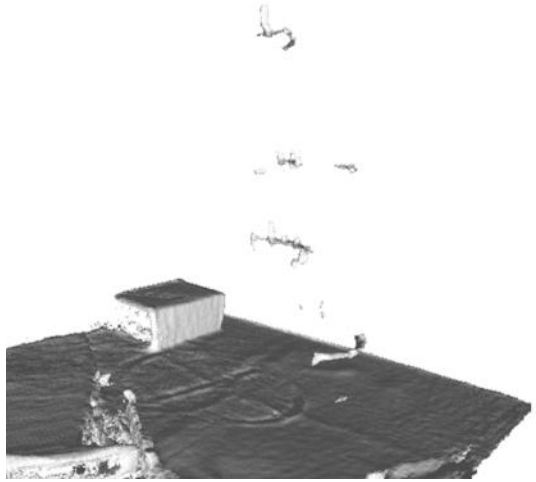
Input



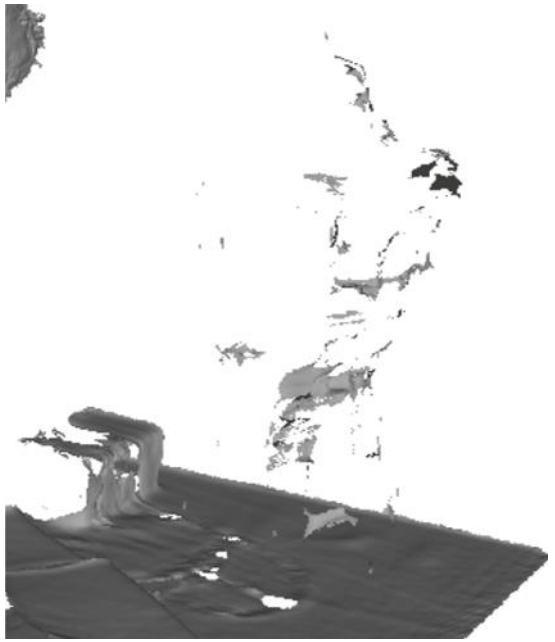
Reference



Volume Fusion[1]



Kinect Fusion[2]



Bundle Fusion[3]

[1] Curless et al. "**A volumetric method for building complex models from range images.**" SIGGRAPH 1996.

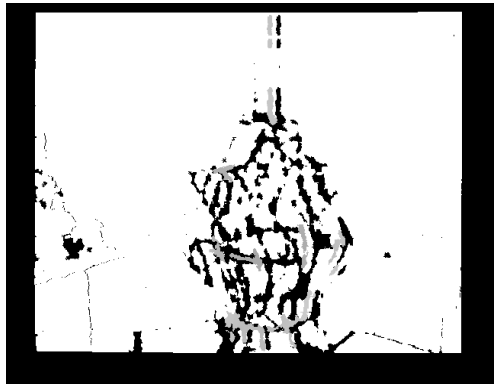
[2] Newcombe et al. "**KinectFusion: Real-time dense surface mapping and tracking.**" ISMAR 2011.

[3] Dai et al. "**Bundlefusion: Real-time globally consistent 3d reconstruction using on-the-fly surface reintegration**." TOG 2017.

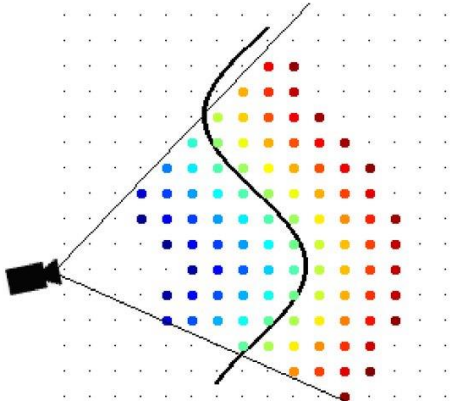
Our Reconstruction Result

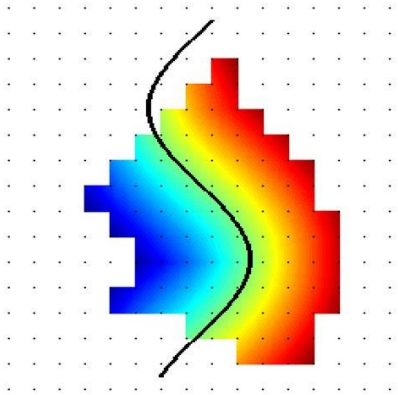
Key Challenges in Wire Reconstruction

1) Noisy depth samples and missing thin structures



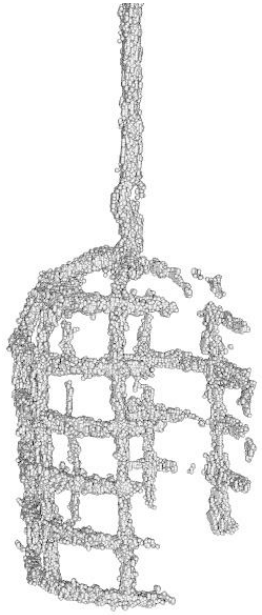
2) Voxel grid cannot represent thin structures well





Curve Skeleton – A New Fusion Primitive

Extract skeletons from depth images



point cloud

curve skeleton

Scanning Video

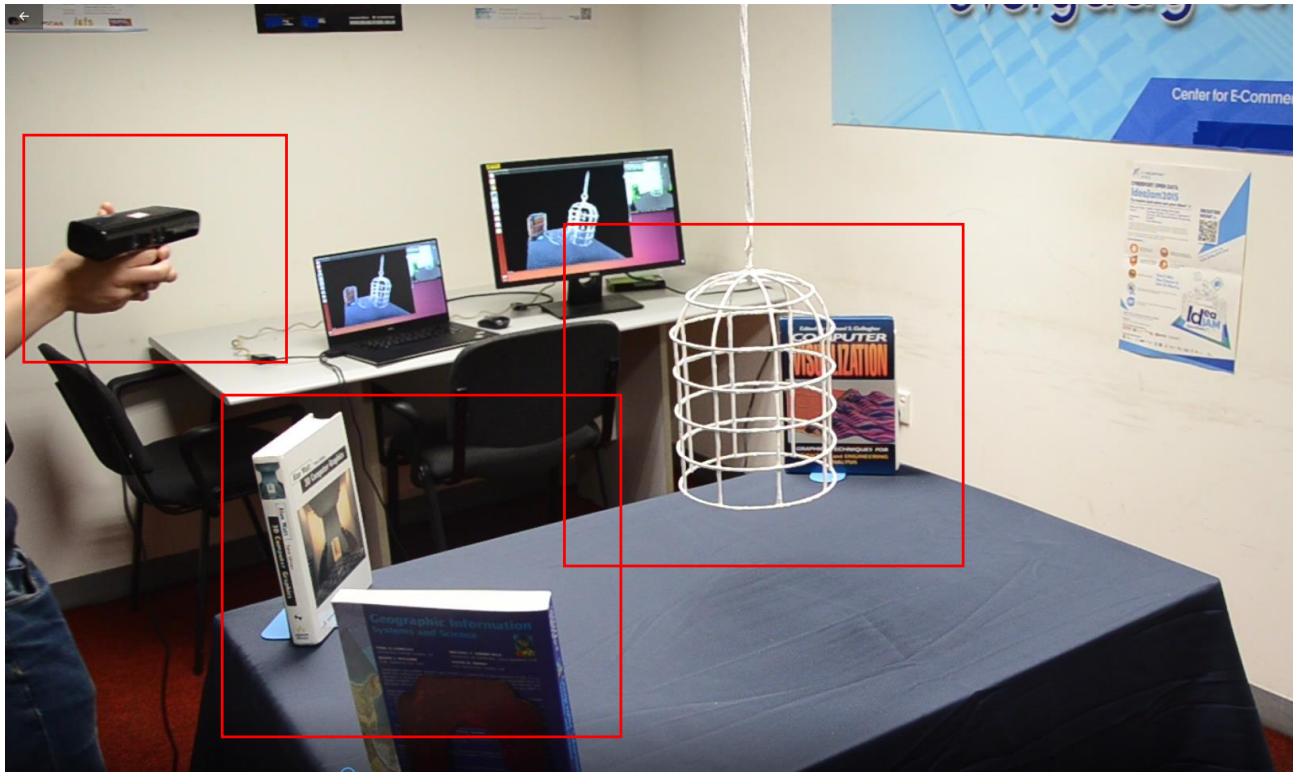
System Setup and Assumptions

System Setup:

- Kinect V1 sensor
- ORB SLAM [1] for camera pose

Assumptions:

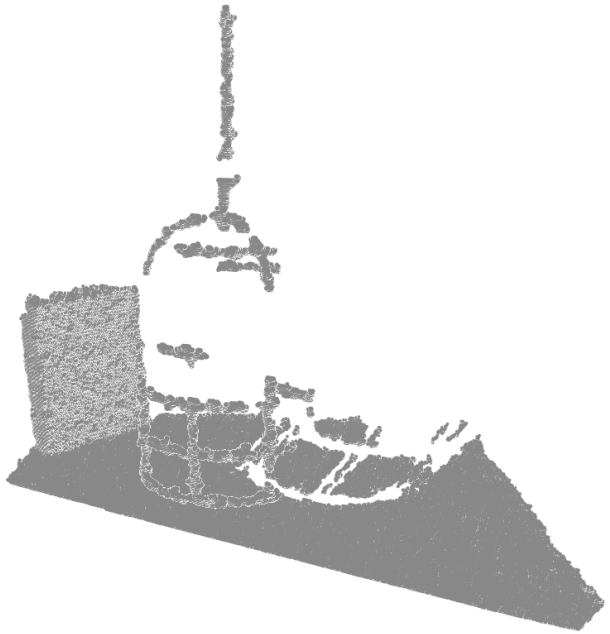
- Sufficient features in background
- Wires of diameter 2 mm and up
- Non-black surface color



[1] Mur-Artal et al. "ORB-SLAM: a Versatile and Accurate Monocular SLAM System.“ IEEE Transactions on Robotics, 2015

Key Issue #1: Data Segmentation

Separating point samples of thin structures from background

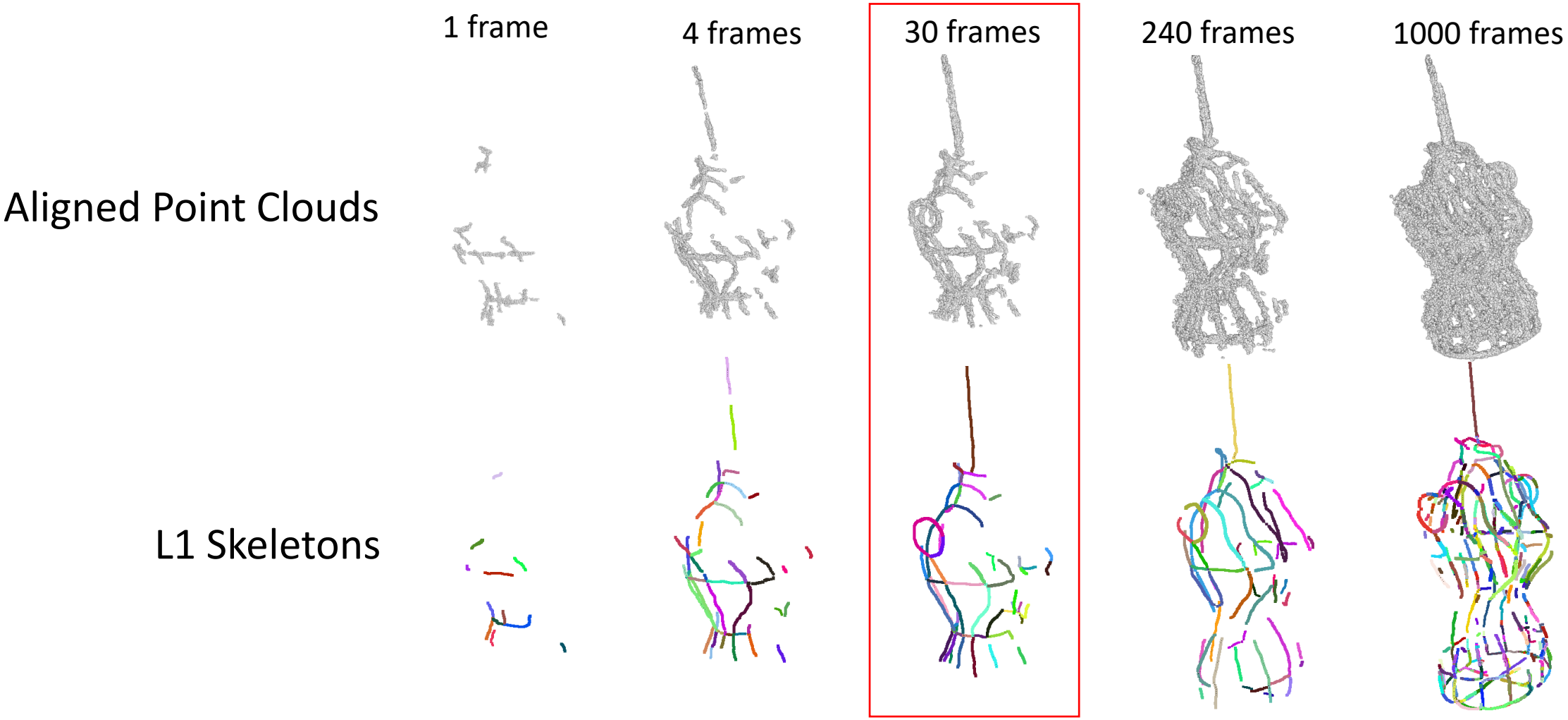


A full depth frame

Depth samples of the thin structure

Key Issue #2: Data Consolidation

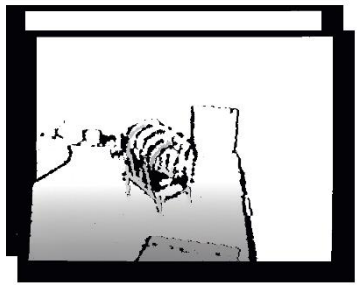
Group depth frames into bundles for data consolidation



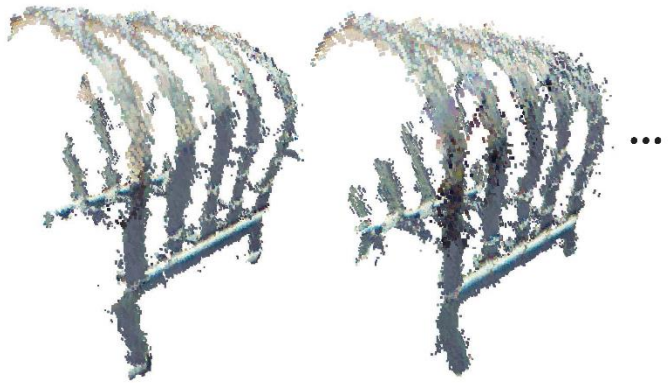
Algorithm Pipeline of CurveFusion

1) Perform segmentation to obtain bundles of depth samples on the thin structure
2) Extract a partial skeleton from each bundle of depth samples
3) Fuse all partial skeletons to form the complete skeleton of the whole wire model

input RGBD frames

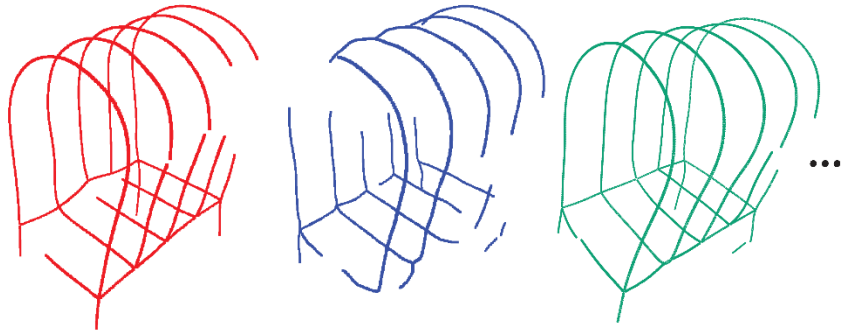


Point Cloud Segmentation



bundle 1 bundle 2

Skeleton Fusion



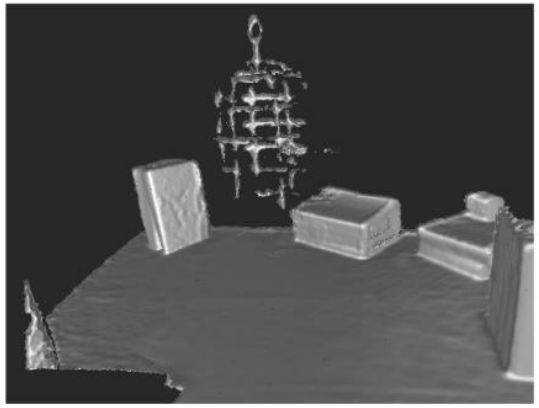
current fused skeleton + new bundle skeleton = updated fused skeleton

output thin structure reconstruction

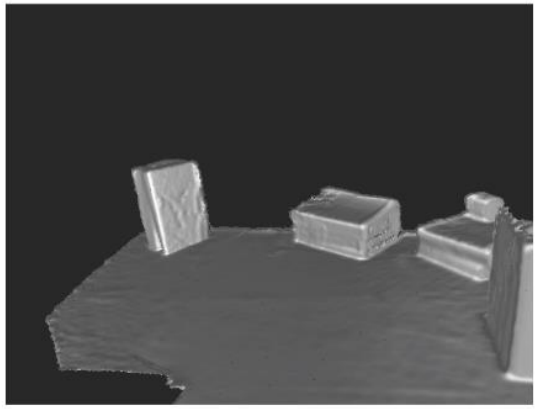
Segmentation Procedure

(a) input bundle

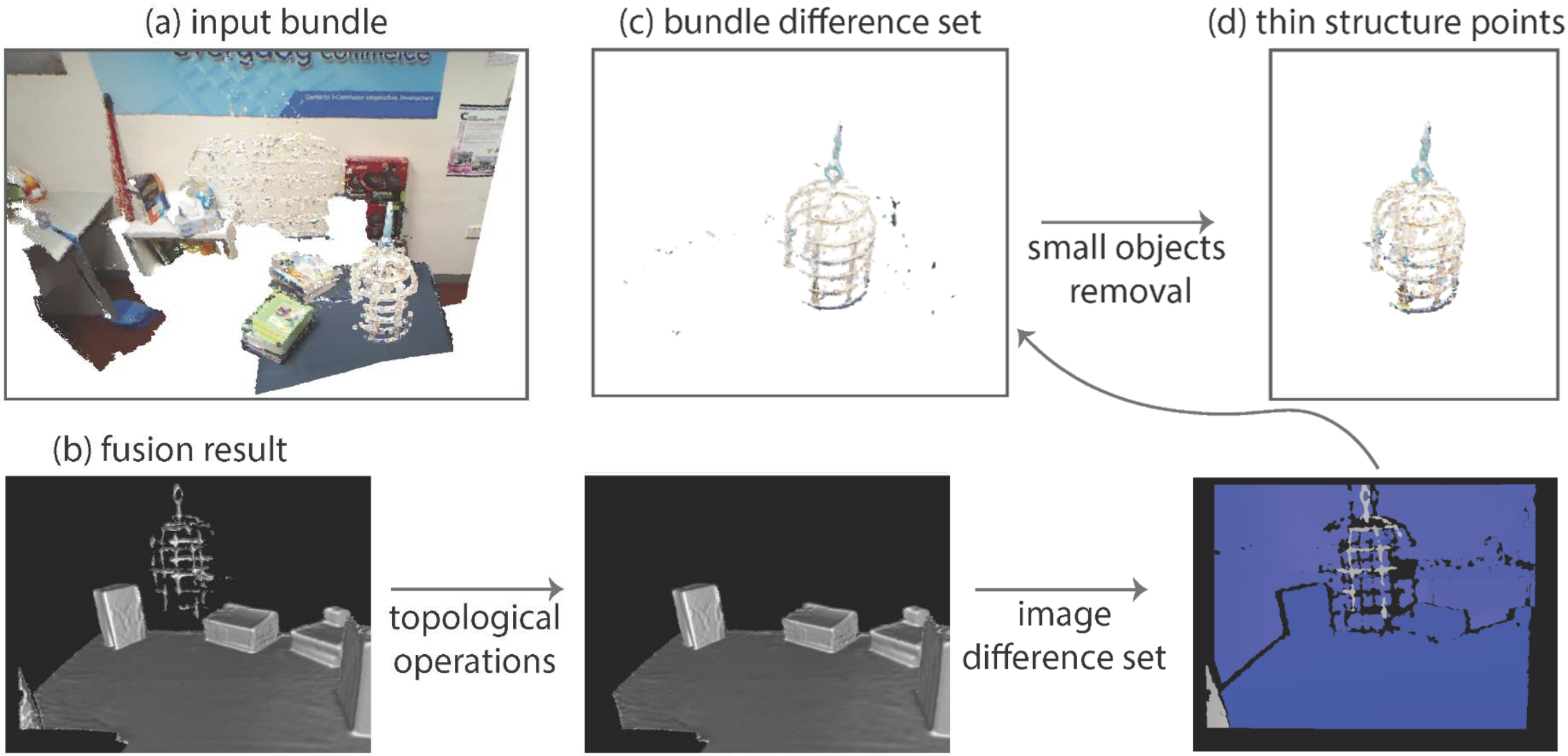
(b) fusion result



topological operations

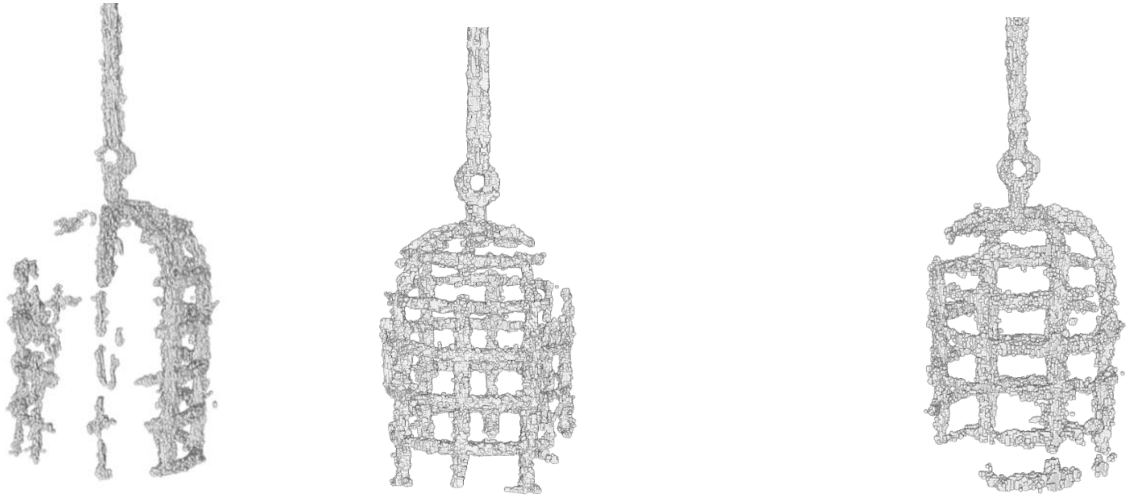


Segmentation Procedure



Extracting Curve Skeletons: L1 Skeleton[1]

Bundle Point Cloud

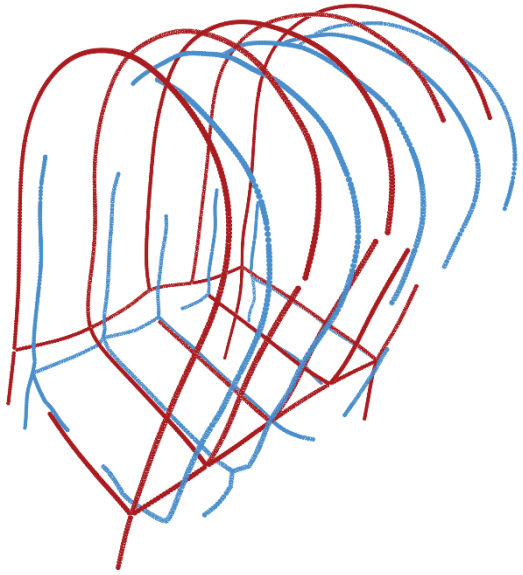


L1 Skeletons

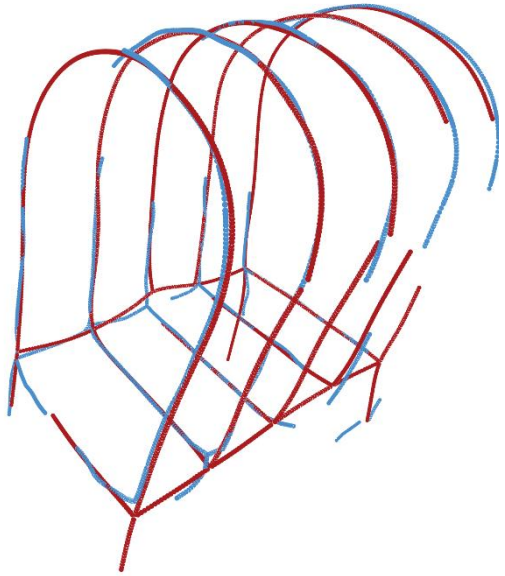
Aligned Skeletons

[1] Hui Huang, Shihao Wu, Daniel Cohen-Or, Minglun Gong, Hao Zhang, Guiqing Li, and Baoquan Chen. 2013. L1-medial Skeleton of Point Cloud. In ACM SIGGRAPH. ACM, New York, NY, USA, Article 65, 8 pages.

Fusing Bundle Skeletons Together

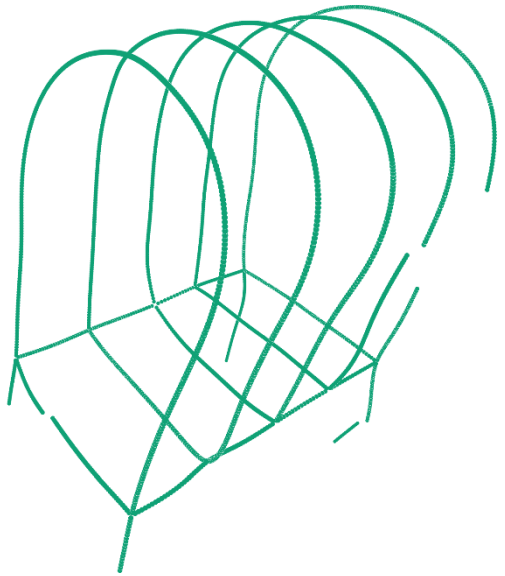


Bundle skeleton and fused partial skeleton



After alignment

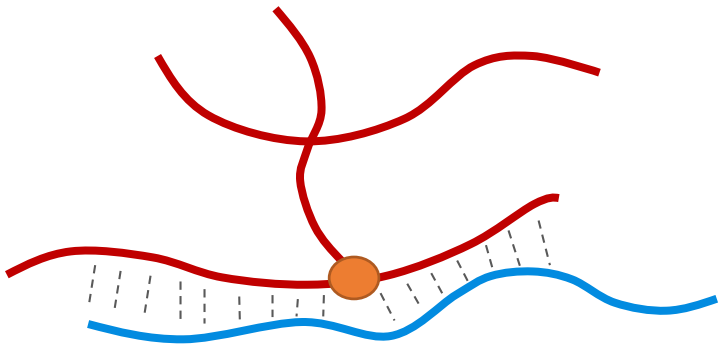
After merge



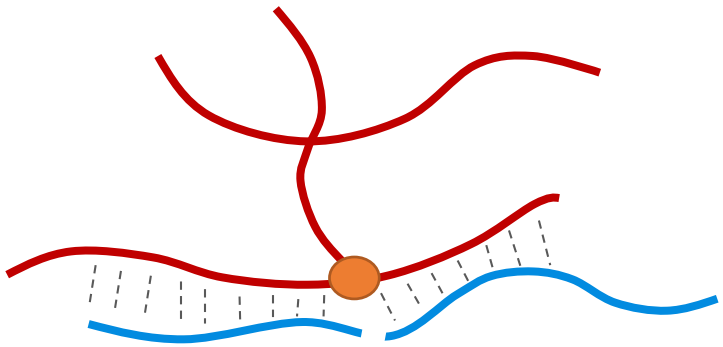
New partial skeleton

Red: Already Fused Partial Skeleton
Blue: New Bundle Skeleton
Green: New Partial Skeleton

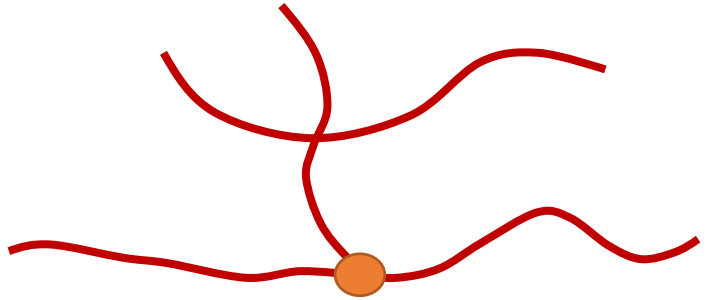
Fusing Bundle Skeletons Together



before merge



curve splitting

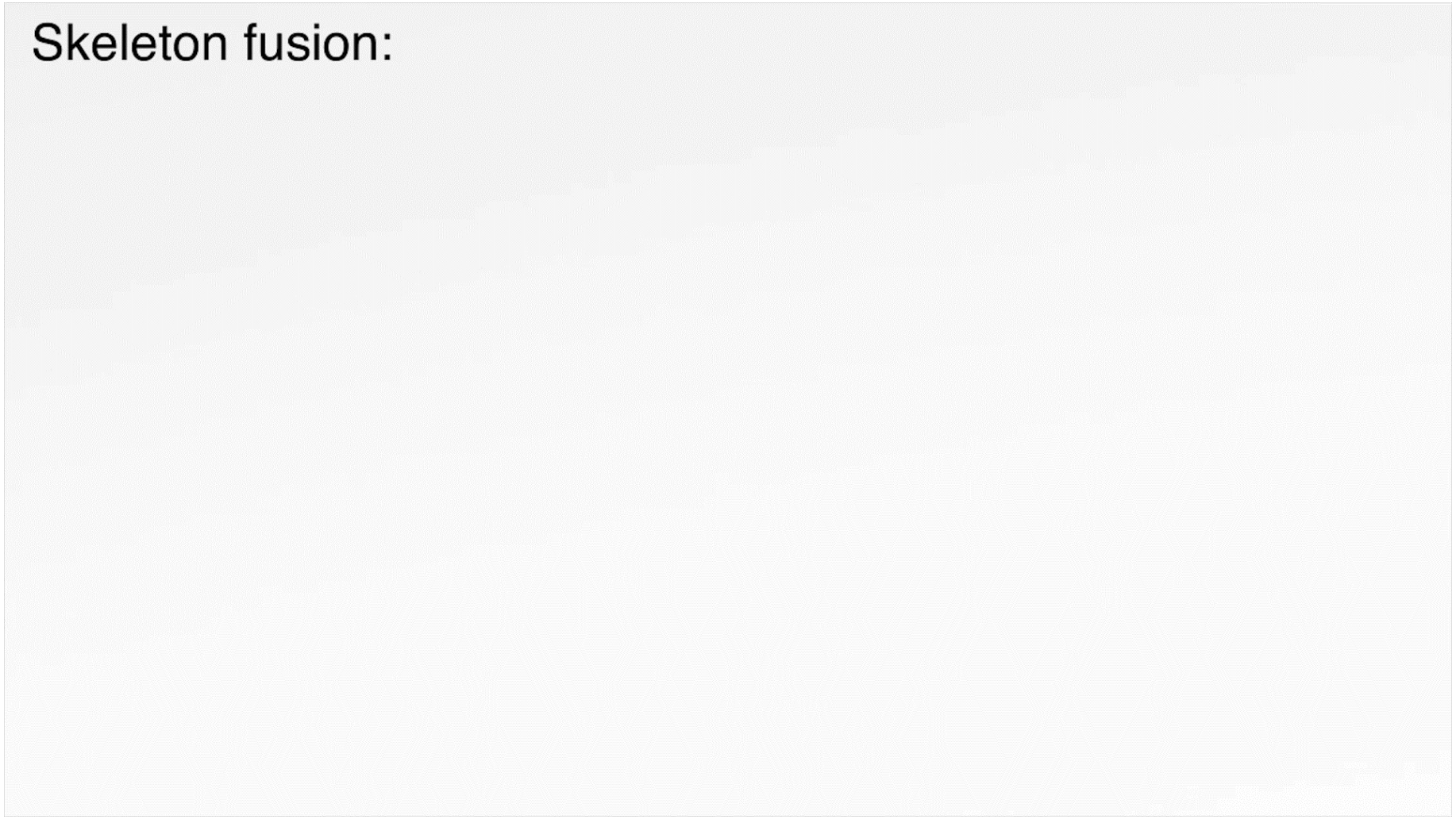


after merge

Red: Already Fused Partial Skeleton

Blue: New Bundle Skeleton

Fusing Bundle Skeletons Together



Results

RGB Images | Ground Truth | Our Results

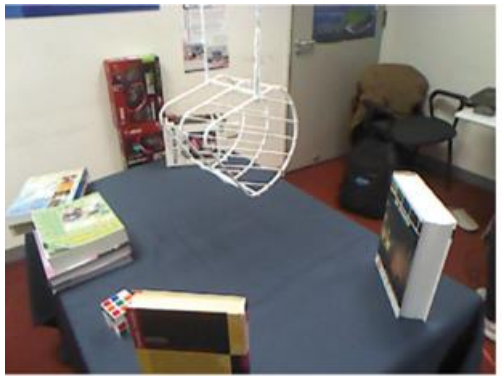




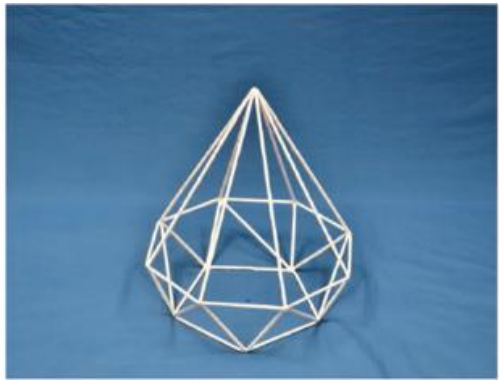



Results

RGB Images



Ground Truth

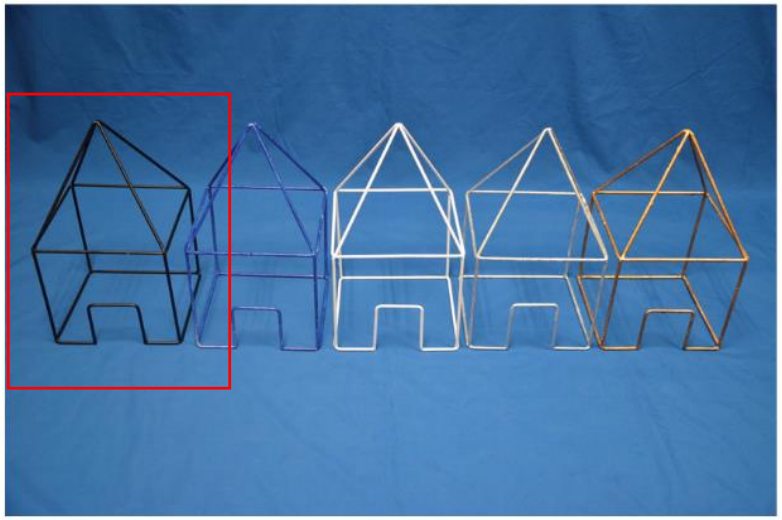


Our Results

Evaluation – Different Colors

Black objects cannot be scanned

Scanning setup



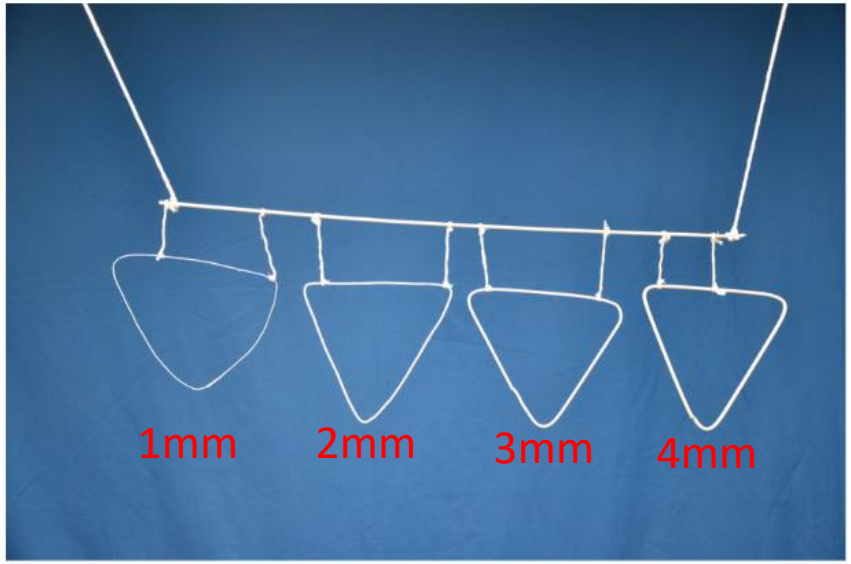
Reference image

Aligned point cloud

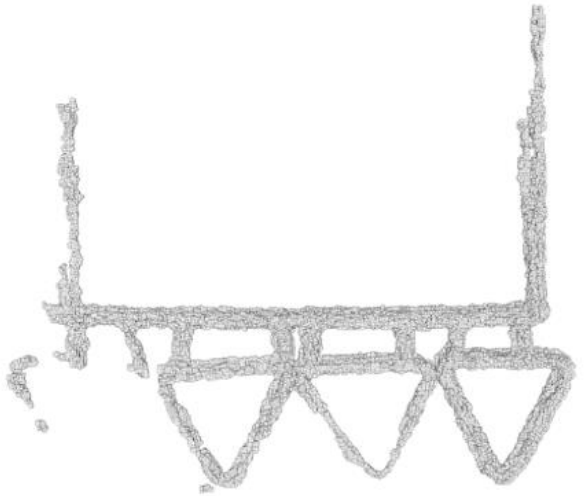
Evaluation – Different Diameters

Wires of diameter less than 2 mm cannot be captured by Kinect V1

Scanning setup



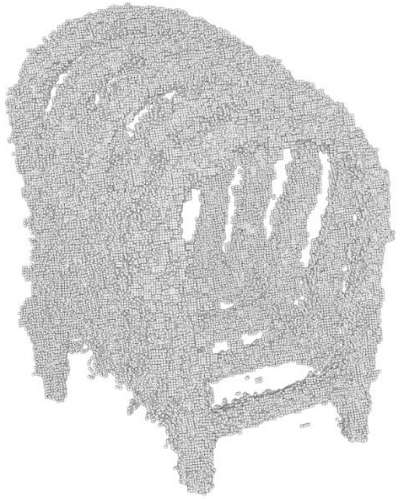
References



Aligned point cloud

Evaluation – Different Camera Pose Estimations

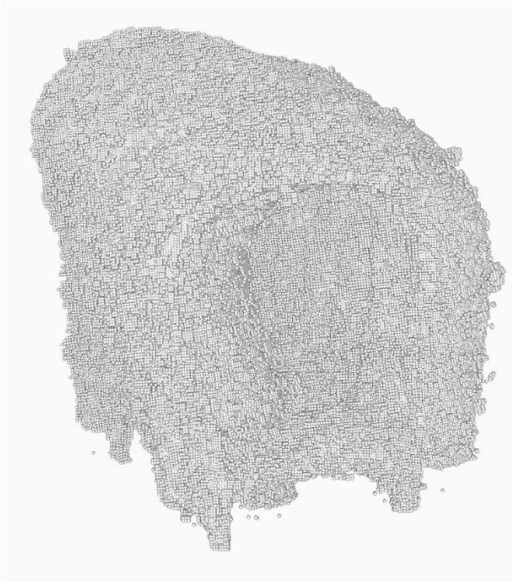
BundleFusion[1]



Aligned point cloud

Our reconstruction

KinectFusion[2]



Aligned point cloud

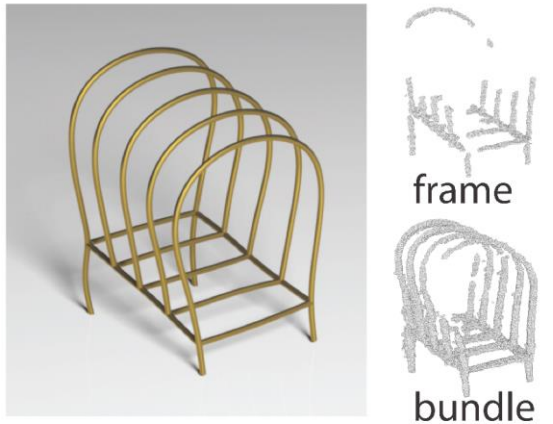
Our reconstruction

[1] Angela Dai, Matthias Nießner, Michael Zollhöfer, Shahram Izadi, and Christian Theobalt. 2017. **BundleFusion: Real-Time Globally Consistent 3D Reconstruction Using On the Fly Surface Reintegration.** ACM TOG 36, 3, Article 24 (May 2017), 18 pages.

[2] Richard A. Newcombe, Shahram Izadi, Otmar Hilliges, David Molyneaux, David Kim, Andrew J. Davison, Pushmeet Kohli, Jamie Shotton, Steve Hodges, and Andrew Fitzgibbon. 2011. **KinectFusion: Real-time Dense Surface Mapping and Tracking.** In IEEE ISMAR (ISMAR '11). IEEE Computer Society, Washington, DC, USA, 127–136.

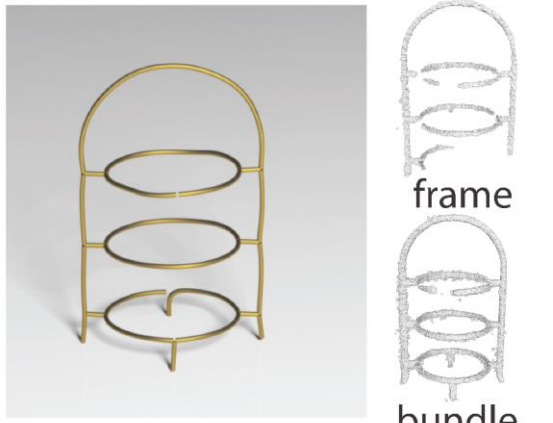
Evaluation – Different Sensors

PrimeSense



frame

bundle



frame

bundle

RealSense

FAILED

frame

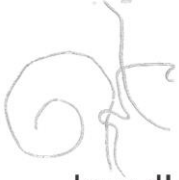
bundle

frame

bundle

Artec Space Spider

frame

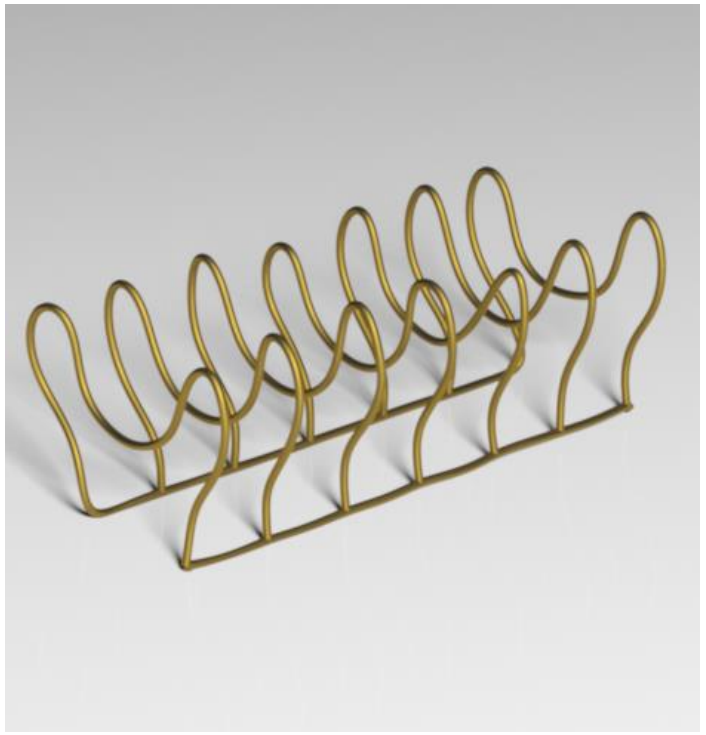


bundle

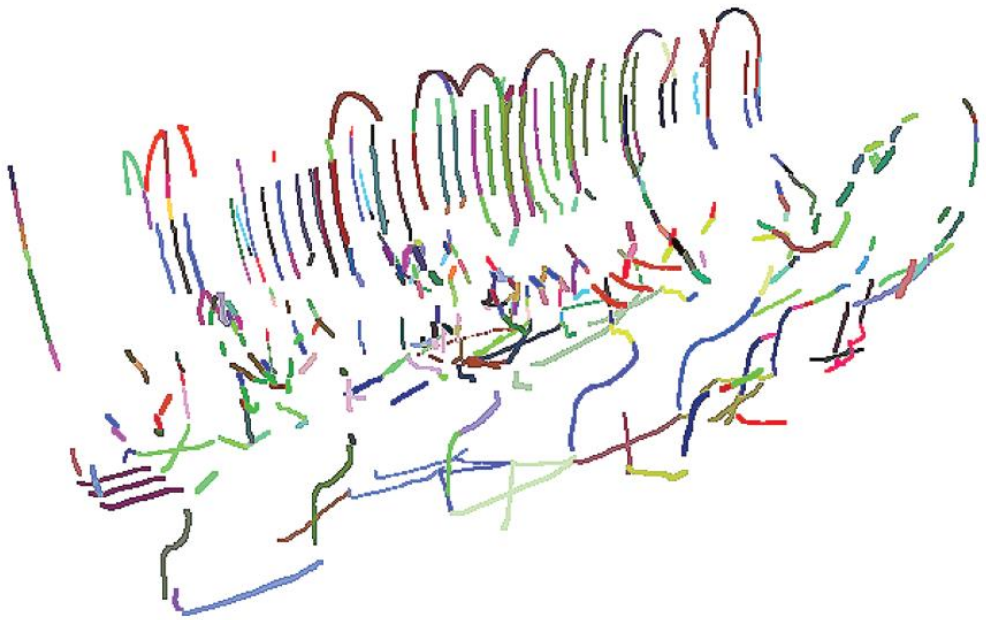
Comparison with [Liu et al. 2017]

Reference Image

Our Result



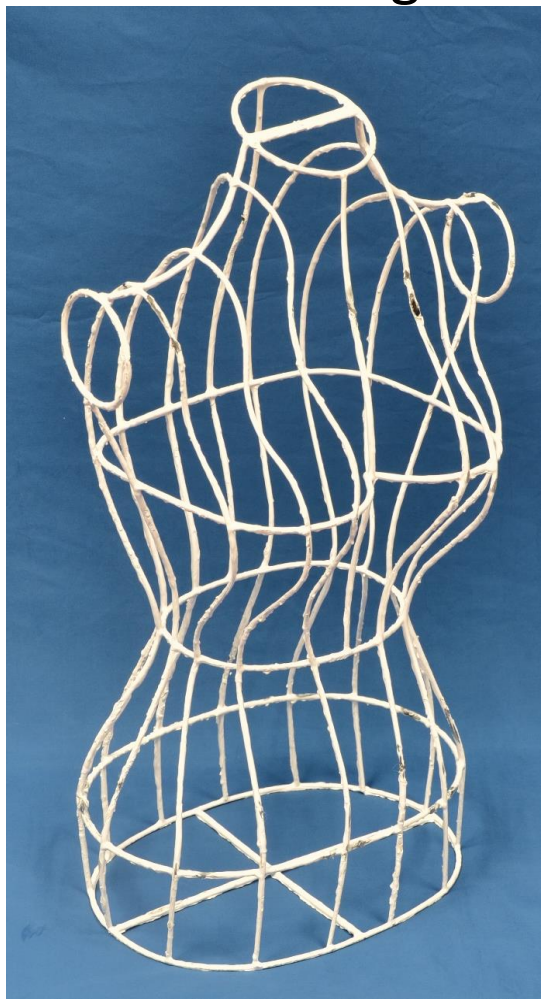
Liu et al. 2017



Lingjie Liu, Duygu Ceylan, Cheng Lin,WenpingWang, and Niloy J. Mitra. 2017. **Imagebased Reconstruction of Wire Art.** ACM SIGGRAPH 36, 4, Article 63 (July 2017), 11 pages.

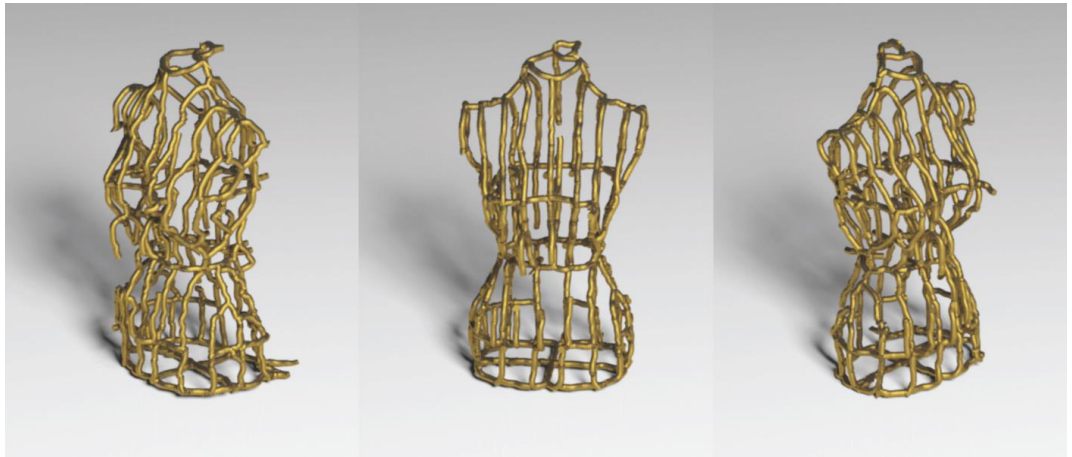
Comparison with [Tabb et al. 2013]

Reference Image



Our Result

Tabb et al. 2013



A. Tabb. 2013. **Shape from Silhouette Probability Maps: Reconstruction of Thin Objects in the Presence of Silhouette Extraction and Calibration Error.** In 2013 IEEE Conference on Computer Vision and Pattern Recognition.

Limitations

1. Cannot scan black wires or wires of diameter less than 2 mm
2. Cannot reconstruct dynamic wires
3. Wires are assumed to have a constant radius
4. Reconstruction is not real time.

Future Works

1. Real time performance
2. Thin structures of varying radius or non-circular cross-section
3. Hybrid structures

Reference

Preliminary result

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- Thank **Cheng Lin, Jiatao Gu, Maria Lam, Paul Guerrero** for their help.

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Thank You!

...

reference image

our reconstruction