CSE-571
Mapping and Modeling
Using Truncated Signed Distance Functions

Based on work by Peter Henry
University of Washington

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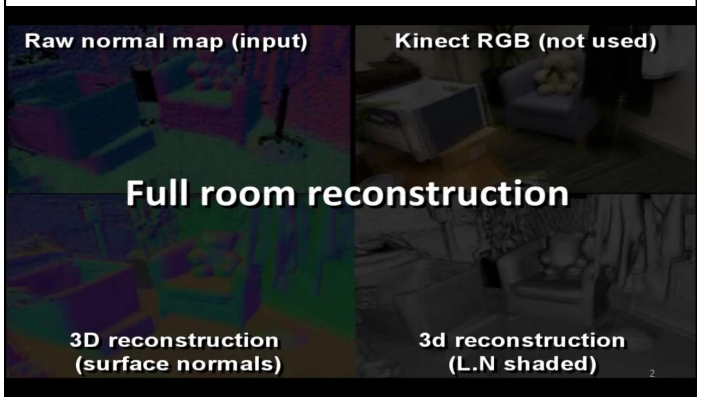
KinectFusion: Real-Time Dense Surface Mapping and Tracking.
Newcombe et al. ISMAR 2011



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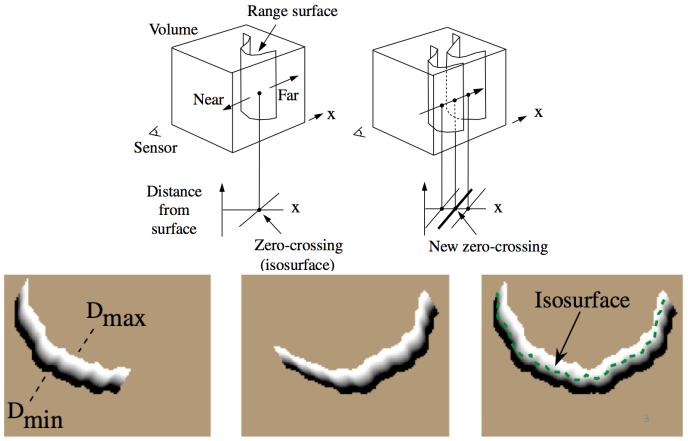
[Slide: Brian Curless]

Truncated Signed Distance Function (TSDF)



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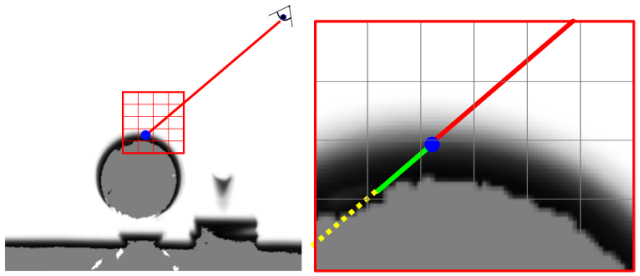
[Slide: Richard Newcombe]

TSDF Surface Prediction



A regular grid holds a discretistion of the SDF. Ray-casting of iso-surfaces S. (Parker et al. 1998) is an established technique in graphics.

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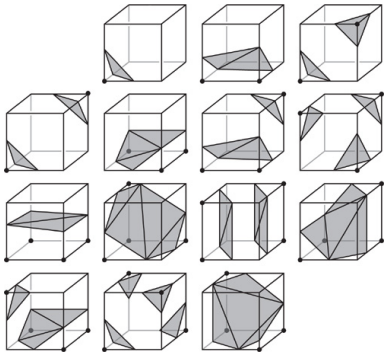
[Slide: Nvidia GPU Gems]

TSDF Mesh Extraction: Marching Cubes



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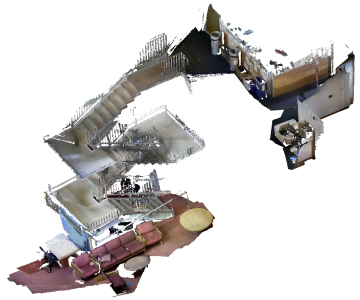
Kintinuous: Spatially Extended KinectFusion.
Whelan et al. RSS RGB-D Workshop 2012
Robust Real-Time Visual Odometry for Dense RGB-D Mapping.
Whelan et al. ICRA 2013
Deformation-based Loop Closure for Large Scale Dense RGB-D SLAM
Whelan et al. IROS 2013 (contemporaneous)



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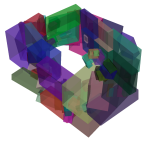
Patch Volumes

- Model: A collection of fusion volumes
  - Allocate volumes based on planar patches
  - Save memory: model only occupied space
  - Enable arbitrary scale
  - Shift volumes for global consistency



Patch Volumes: Segmentation-based Consistent Mapping with RGB-D Cameras.
Henry, Fox, Bhowmik, Mongia. 3DV 2013

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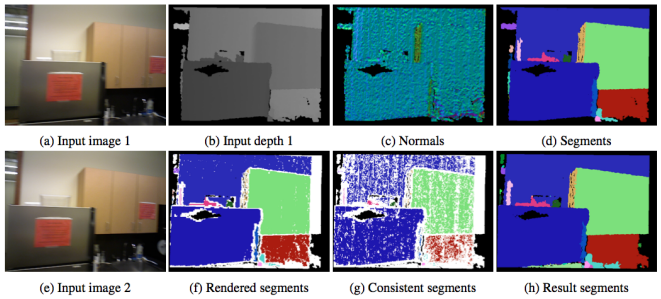
Patch Volume Segmentation



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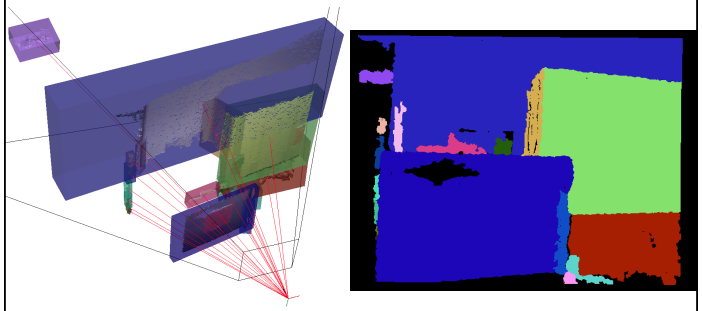
Patch Volumes in 3D



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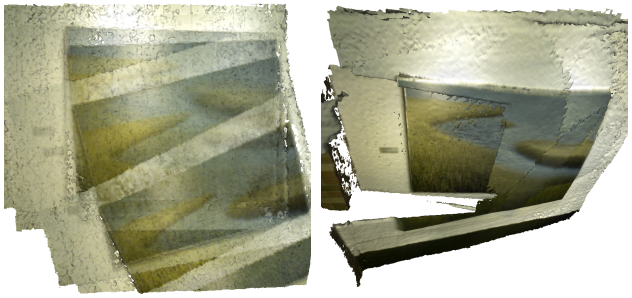
Depth & Color Both Matter

Depth Only: **Color Only:**



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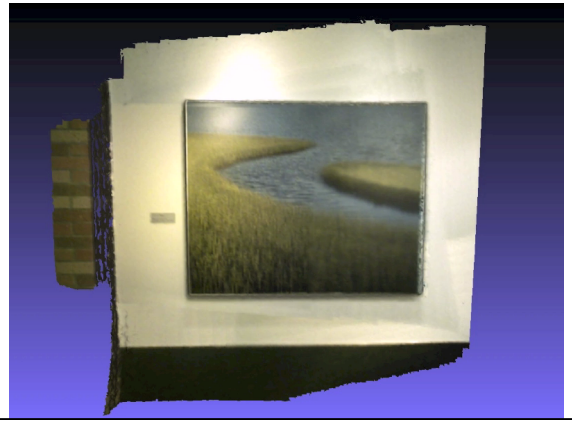
Depth & Color Both Matter



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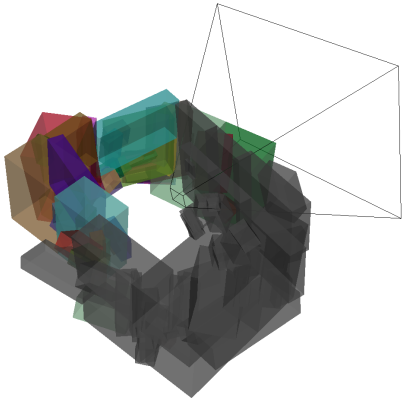
Global Consistency: Patch Volumes Grow Old



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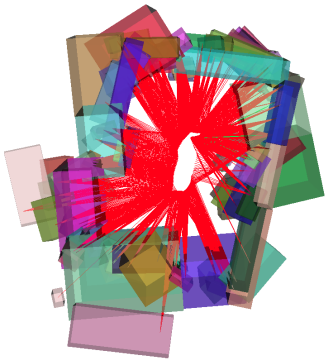
Loop Closure Alignment

- Initialize with feature matching
- Run dense alignment against “old” volumes

Before feature matching | After feature matching and dense alignment

Graph Optimization



g2o: A General Framework for Graph Optimization.
Kuemmerle et al. ICRA 2011

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Global Consistency Matters

No Loop Closure:

With Loop Closure:

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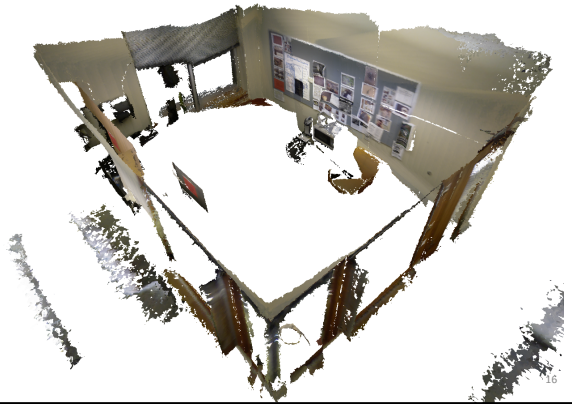
Result Overview



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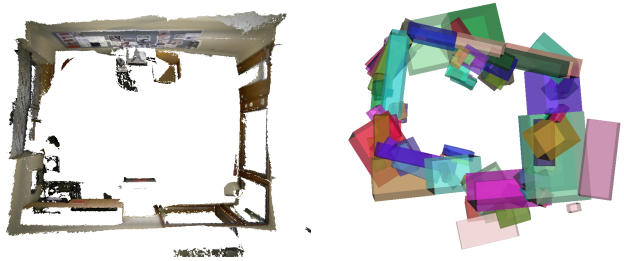
Result Overview



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A More Complete Model

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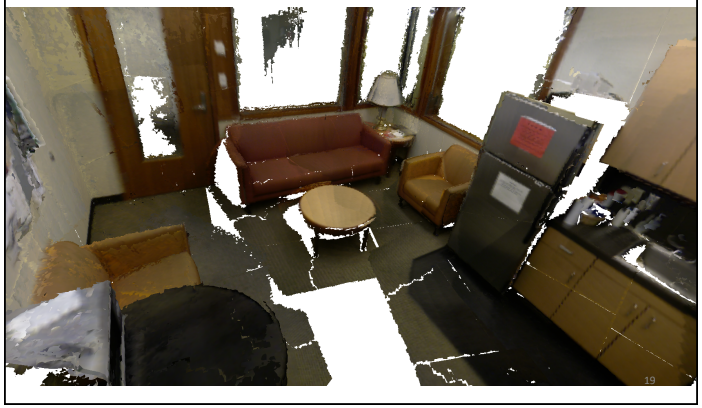
A More Complete Model



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Thin Surfaces

Single Volume (color bleeding, size inflation)

Patch Volumes

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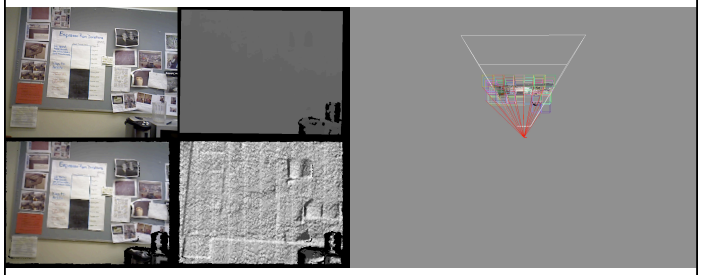
Regular Grid



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Regular Grid

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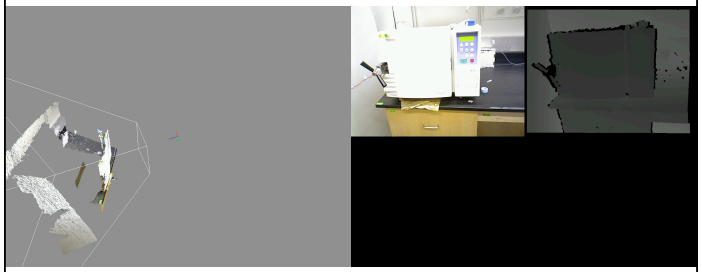
Wetlab



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Wetlab

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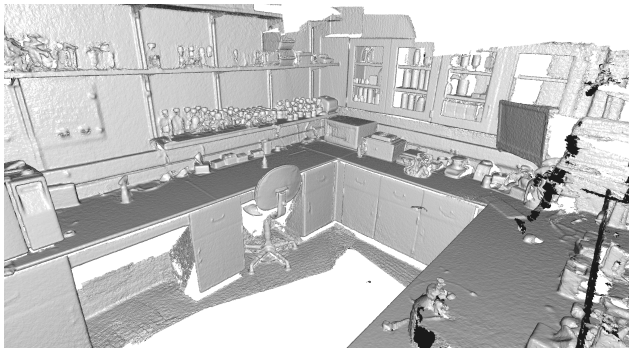
Wetlab



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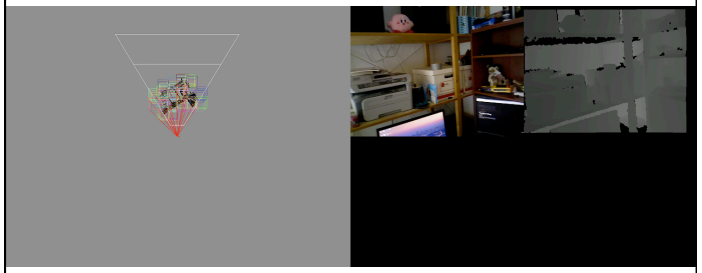
House



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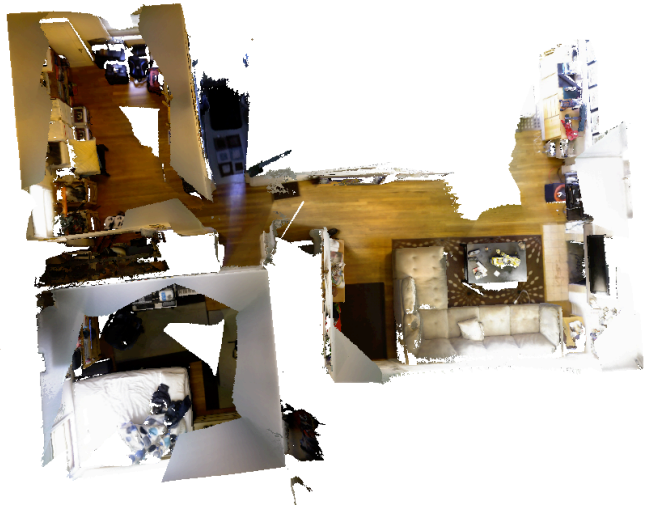

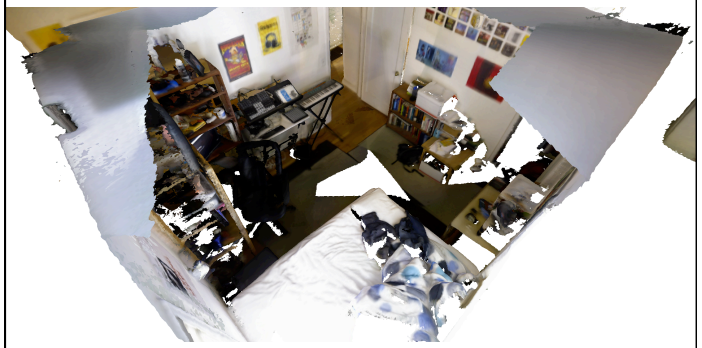

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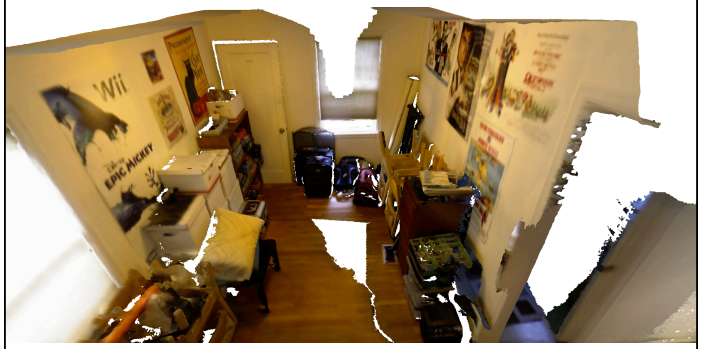

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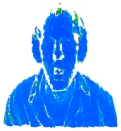
Real-Time Reconstruction and Tracking of Non-rigid Scenes

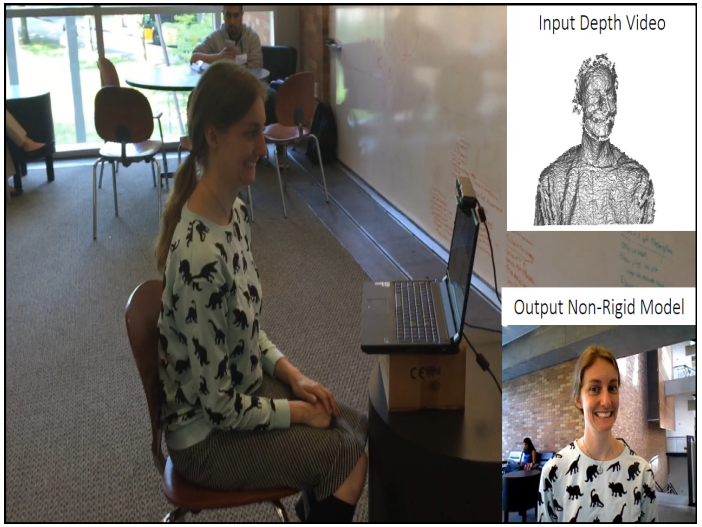
DynamicFusion

KinectFusion on a Non-rigid Scene

Model



Model-Frame Error



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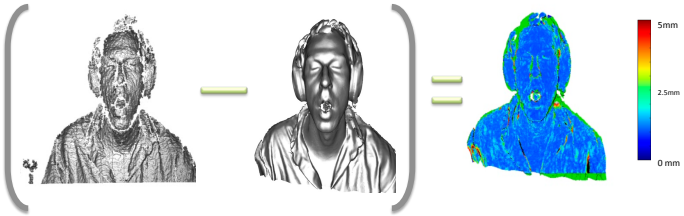
Dense Non-Rigid Surface Tracking

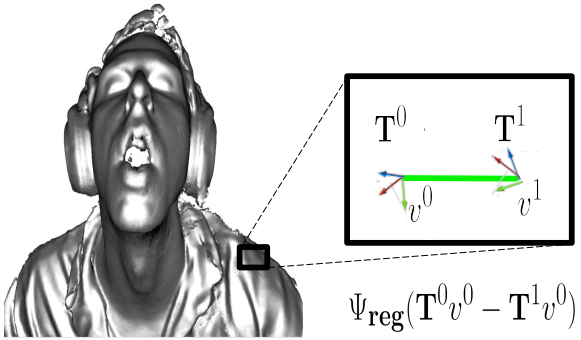
Live Depth Video

$\mathrm{Data}(\mathcal{W}_t, \mathcal{V}, D_t)$: Dense Per-Pixel Data Term

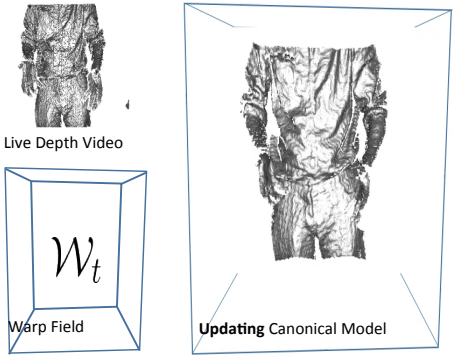


Per-Pixel **Projected Model-to-Frame** Point-Plane Error

$\mathrm{Reg}(\mathcal{W}_t, \mathcal{E})$: as-Rigid-as-possible

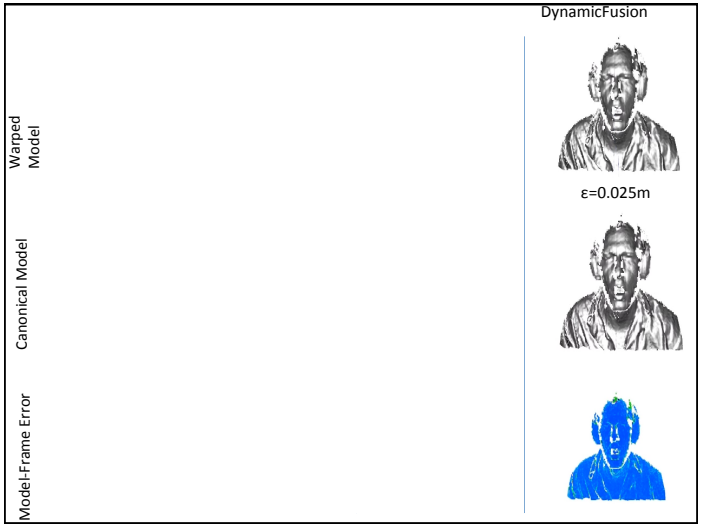


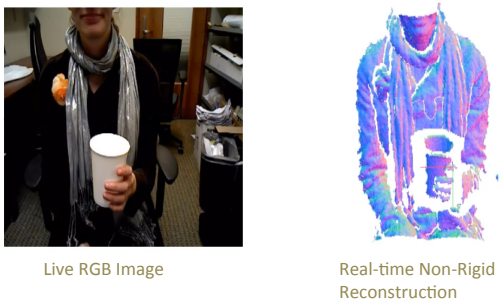
Non-Rigid Generalisation of Range Image Fusion



Algorithm Summary

- **Given: Canonical model and warp field at pervious time step**
- **Update Warp Field**
  - Extract surface mesh from canonical (static) SDF model
  - Update warp nodes via non-rigid alignment to depth image
- **Update Canonical SDF Model**
  - Use updated warp field to project each SDF voxel into depth frame and update SDF value
- **Update Warp Field Structure**
  - Add new warp nodes if necessary, update regularization structure




Live RGB Image

Real-time Non-Rigid Reconstruction

Live RGB Image

Real-time Non-Rigid Reconstruction

Limitations

- **Reconstruction Scalability**
  - Volumetric surface representation
  - Tracking of Motion not in the live frame
- **Tracking Failures**
  - Closed to Open Topology Changes
  - No Explicit Loop closure

Initializing DynamicFusion

Learning to Solve Long-Range Dense Correspondence using Generatively Tracked Short-Range Non-Rigid Correspondences