Efficient Online Surface Correction for Real-time Large-Scale 3D Reconstruction

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Motivation
Real-time large-scale 3D reconstruction:
- Global pose optimization to reduce drift
- Usually no surface update on pose changes

Goal: correct 3D surface on-the-fly on pose changes

Contributions
- Efficient on-the-fly surface correction for large-scale dense 3D reconstruction (single GPU)
  - Keyframe fusion of RGB-D frames using different keyframe strategies
  - Re-integrate fused keyframes into sparse SDF volume on pose updates
  - Efficient re-integration strategy: reduced host-GPU-streaming
  - 93% more efficient than state-of-the-art (equivalent surface quality)
- Combination with dense Visual SLAM system (CPU)

3D Reconstruction System
System Pipeline

RGB-D frames → DVO-SLAM → initial poses → Keyframe Fusion → keyframes → SDF Volume

DVO-SLAM: Dense Visual RGB-D SLAM [1]
- Frame-to-frame tracking using robust dense visual odometry
- Loop closure detection and continuous pose graph optimization

Keyframe Fusion
- Depth fusion (weighted mean of warped input depth maps)
- Color fusion (unsharp masking, blurriness, weighted median)

Efficient Online Surface Re-integration

Keyframe Strategies
- Selection of independent keyframes for fusion
  - number of fused frames per keyframe k
- Strategies: Constant, DVO, Distance, Overlap

On-the-fly Surface Correction
- Integrate keyframes into SDF volume with original poses
- On DVO-SLAM pose graph updates:
  - Select m changed keyframes for re-integration
  - De-integrate keyframes at original poses
  - Re-integrate on-the-fly with updated poses

Re-integration Strategy
- BundleFusion [2] strategy: select m most-moved frames
- Better: select group of most-moved m consecutive keyframes
  \[ f = \arg\max_{j\in[1,K-m+1]} \sum_{i=j}^{j+m-1} \| s_i - s_i' \| \]
  - Significantly reduced GPU-host-streaming!
- Example: BundleFusion (12, 8, 13, 5, 3) vs. ours (4 to 8)

References

Evaluation and Experimental Results
Surface Completeness/Correctness vs. Frames per Keyframe
AUG_ICL/Liv1
Correctness (k=5 vs. k=60) Completeness (k=5 vs. k=60)

Runtime Evaluation
93% more efficient compared to BundleFusion [2] (k=20, m=5)

Qualitative Results: On-the-fly Surface Re-integration
Without (left) and with (right) online surface correction
BundleFusion/opt0

TUM/long_office_household

Final

i = 1750
ElasticFusion [3]
Ours

Final
ElasticFusion [3]
Ours

Qualitative Comparison: ElasticFusion [3]