Kinect Fusion: Real-time 3D Reconstruction and Interaction Using a Moving Depth Camera

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Overview

Difficult goal

3D reconstruction of an indoor scene

Use single depth camera
  ◦ Estimate pose of camera
  ◦ Compare depth map
  ◦ Update 3D reconstruction

Low-cost and real-time

Related Work:
  ◦ Active sensors
  ◦ Passive cameras
  ◦ Online Images
  ◦ Simultaneous Localization and Mapping (SLAM)
Design Goals

Interactive rates for camera tracking and reconstruction
- Direct feedback
- User interaction

No explicit feature detection
- Camera tracking avoids explicit detection step
- Works on depth maps

High-quality reconstruction of geometry
Design Goals

Dynamic interaction assumed
- user interaction is possible
- Dynamically changing scenes

Infrastructure-less
- Reconstruct arbitrary indoor spaces

Room scale
- Support room reconstructions and interaction
KinectFusion System

Construct 3D model of the scene:
- Track 6DOF pose of camera
- Fuse live depth data into a 3D model

User explores the space
- New views
- Reconstruction grows
- Image super-resolution
Examples
Object Segmentation

Scan specific physical object
- Monitor 3D reconstruction
- Observe changes over time
- Segment repositioned object
Geometry-Aware Augmented Reality

3D virtual world is overlaid onto the real world
Taking Physics Beyond the Surface

Simulate real-world physics.
Reaching into the Scene

User interaction
- Static scene -> dynamic scene
- Robust to transient and rapid scene motions
- Problems with prolonged interactions
  - User moves in front of the camera

Special GPU-based pipeline
- Geometry of background scene
- Geometry of the foreground user

Determine interactions
System pipeline

a) Depth Map Conversion (Raw Vertex & Normal Map)
b) Camera Tracking (ICP)
c) Volumetric Integration
d) Raycasting (3D Rendering)
Camera Tracking

Iterative Closest Point (ICP)
- Projective data association
- Find correspondences between oriented points

Output: relative transformation matrix that minimizes the point-to-plane error metric

Dense tracking

Listing 1 Projective point-plane data association.

```plaintext
1: for each image pixel \( u \) \( \in \) depth map \( D_i \) in parallel do
2:   if \( D_i(u) > 0 \) then
3:     \( v_{i-1} \leftarrow T_{i-1}^{-1} v_{i-1}^g \)
4:     \( p \leftarrow \) perspective project vertex \( v_{i-1} \)
5:     if \( p \in \) vertex map \( V_i \) then
6:       \( v \leftarrow T_{i-1} V_i(p) \)
7:     \( n \leftarrow R_{i-1} N_i(p) \)
8:     if \( \|v - v_{i-1}^g\| < \) distance threshold and \( n \cdot n_{i-1}^g < \) normal threshold then
9:       point correspondence found
```

D: Depth map
T: Global camera pose
V: Vertex map
N: Normal map
R: Rotation matrix
Volumetric Representation

3D volume with fixed resolution

Integrate 3D vertices into voxels using Signed Distance Function (SDF)
- Surface defined by the zero-crossing

Truncated Signed Distance Function (TSDF)

3D voxel grid is allocated on the GPU as aligned linear memory

Listing 2 Projective TSDF integration leveraging coalesced memory access.

```
for each voxel g in x,y volume slice in parallel do
    while sweeping from front slice to back do
        v^g ← convert g from grid to global 3D position
        v ← T_i^{-1}v^g
        p ← perspective project vertex v
        if v in camera view frustum then
            sdf_i ← ||t_i - v^g|| - D_i(p)
            if (sdf_i > 0) then
                tsdf_i ← min(1, sdf_i / max truncation)
            else
                tsdf_i ← max(-1, sdf_i / min truncation)
            w_i ← min(max weight, w_i-1 + 1)
            tsdf^{avg} ← (tsdf_{i-1}w_{i-1} + tsdf_iw_i)/w_i
        store w_i and tsdf^{avg} at voxel g
```
Summary

3D reconstruction and camera pose estimation using single depth camera

Features:
- Novel GPU pipeline – real time
- Low–cost object scanning
- Physics based interaction
- Dynamic content

Future work
- Reconstruction of larger scenes
- More details in the reconstruction
- Open new research topics
References
