Real-time hand pose estimation from depth camera using GPU

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Overview

Depth camera, like in Xbox Kinect, is ubiquitous today.

Our GHand machine learning algorithm estimates 3D hand pose from a depth camera image using an unique two random forest approach:

- **Forest \( F_b \):** Estimates 3D position and orientation of hand.
- **Forest \( F_p \):** Estimates joint angles of our kinematic chain hand model.

Random forests on GPU

Problem: Each pixel traverses trees and tests at each node. Gather results from leaves.

Solution:
- Efficient access: Trees of forest stored as contiguous arrays.
- Storage: Right and left child nodes stored together.
- Depth image stored as 2D texture for efficient access.
- Valid pixel locations are found and compacted. Explicitly cached for performance.

Our algorithm

All steps on GPU: Traversal of random forests, meanshift (to find mode of forest results) and DOT (to pick best matching pose)

Performance: Our CUDA implementation runs real-time at 64FPS or more, a 4x speedup over CPU.

Mean shift on GPU

Mean shift to find mode of 6-dimensional points gathered from \( F_p \).

Solution:
- Enclose points in uniform grid of cell size \( 2b_c \times 2b_c \times 2b_c \) (\( b_c \) is bandwidth).
- Make cell-to-point and point-to-cell map using cell index and GPU sort.
- Compute per-cell centroid and use as seeds for meanshift.
- For all seeds in parallel, compute next centroid by only accessing points in necessary neighbor cells.

DOT comparison on GPU

Aim: Compute similarity score between input and results from \( F_p \). DOT (Dominant Orientation Template) is similar to HOG, but has per-pixel parallelization.

- Transformation maps are first generated for image.
- Image mapped to 2D texture for efficient spatially coherent access.
- Bi-linear interpolation of texture units used to compute depth value of transformed pixel.
- Gradient computed efficiently using fast intrinsic functions.
- Atomic addition used for accumulation of results.

Kinematic chain hand model

- **Skeleton:** 15 joints and 20 bones
- **Degrees of freedom:** 6 DoF for hand base, 27 DoF in total
- **Mesh:** 70K triangles, for realistic synthetic data

Results

Joint error: 30mm lesser than ICCV13[1]
Speedup: 4-5x faster than ICCV13[1]