Computer Vision Systems Programming VO

3D Vision Applications

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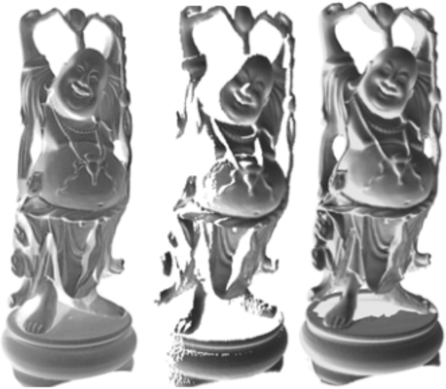
Topics

CV applications utilizing scene geometry (3D data)

- Focus on those based on Kinect

Images by Ryuzo Okada, Shotton et al. 2011, Newcombe et al. 2011

3D Reconstruction



Images from Curless and Levoy 1996

3D Reconstruction

Construction of accurate 3D models from range data

- Usually involves combing multiple point clouds

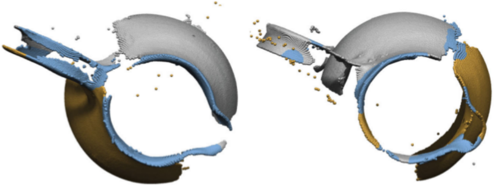
Accomplished in two steps

- Align range data (map to common coordinate system)
- Merge range data in a way that minimizes errors

Often followed by surface reconstruction

Popular method for aligning two point clouds $\{\mathbf{r}\}$, $\{\mathbf{s}\}$

- Goal is to find parameters $\boldsymbol{\theta}$ of some transformation $\mathcal{T}$
- Usually assuming a rigid transformation



Images from Aiger, Mitra, and Cohen-Or 2008

Algorithm iterates between

- Finding point correspondences based on distance, $\{(r_n, s_n)\}_n$
- Finding the $\boldsymbol{\theta}$ that minimizes $\sum_n \|\mathbf{r}_{r_n} - \mathcal{T}(\mathbf{s}_{s_n}; \boldsymbol{\theta})\|_2^2$

Converges towards a local minimum

- Requires good initial estimate of $\boldsymbol{\theta}$

https://www.youtube.com/watch?v=ii2vHBwlmo8

3D Reconstruction

Range Data Merging – TSDF Fusion

Truncated signed distance functions (TSDFs)

- Similar to distance transforms in 3D ($0 = \text{surface}$)
- But distances are signed, measured along view rays

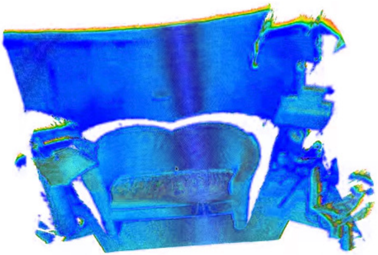
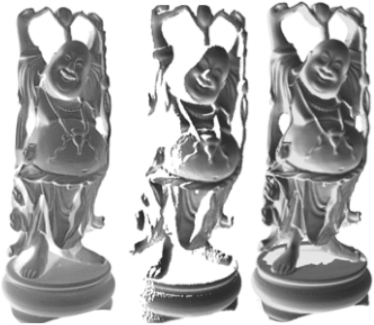


Image from https://www.youtube.com/watch?v=AjjSZufyprU

Merged data = weighted average over aligned TSDF voxels

- Weights based on e.g. object distance, angle

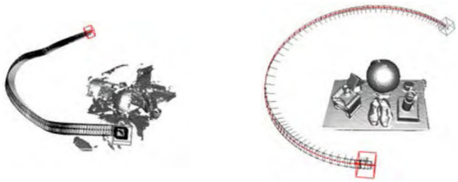


Images from Curless and Levoy 1996

Temporal fusion of Kinect depth maps

Based on the above methods (ICP & TSDF fusion)

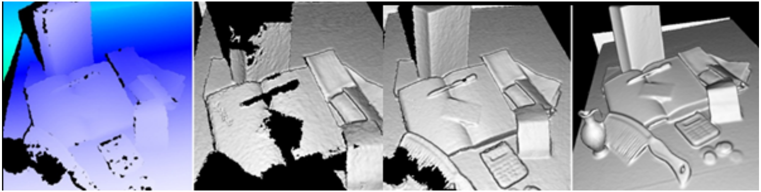
- But $\{\mathbf{r}\}$ is synthesized from merged model
- Suppresses alignment error accumulation



Images from Newcombe et al. 2011

3D Reconstruction
Kinect Fusion

https://www.youtube.com/watch?v=quGhaggn3cQ



Images from microsoft.com

Reconstruction of surface mesh from point cloud

- Results in a (locally) watertight 3D model
- Allows for further processing (e.g. texturing)

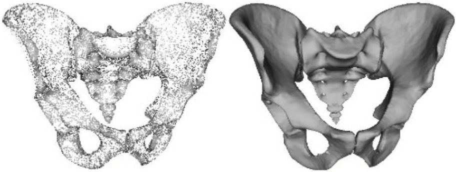


Image from Kazhdan 2005

Correction of point cloud errors

- Noise, outliers, alignment errors, missing data

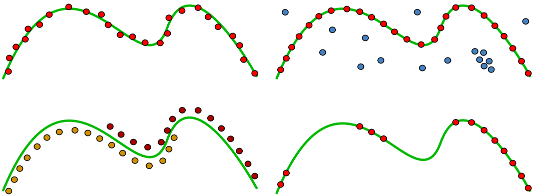
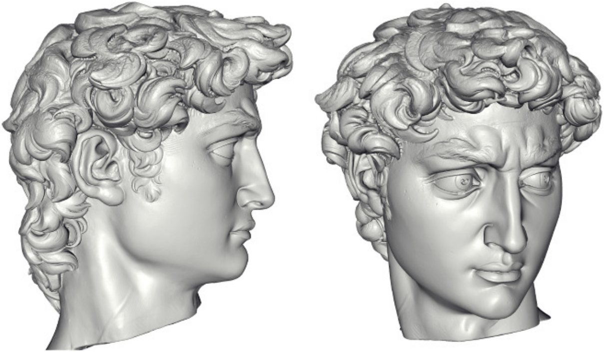


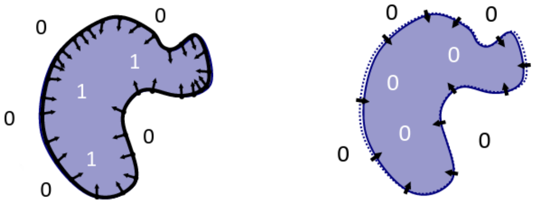
Image adapted from Berger et al. 2014



Images from Kazhdan, Bolitho, and Hoppe 2006

Define $\chi(\mathbf{x}) = 1$ if $\mathbf{x}$ inside the object, 0 otherwise

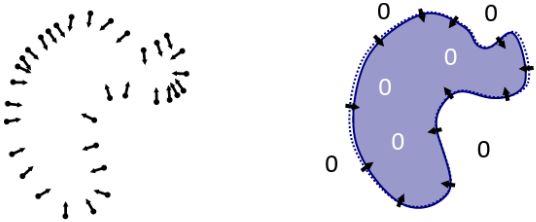
- Surface is at $\chi(\cdot) = 0.5$
- $\nabla\chi$ equals surface normal near surface, 0 otherwise



Images from Gotsman & Kazhdan's slides

Regard oriented points $\{(\mathbf{x}, \mathbf{n})\}$ as samples from $\nabla\chi$, $\nabla\chi(\mathbf{x}) = \mathbf{n}$

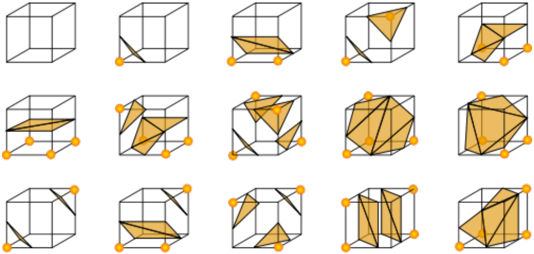
- Points define vector field $\mathcal{V}$ that corresponds to $\nabla\chi$
- Sought χ minimizes $\|\nabla\chi - \mathcal{V}\|$



Images from Gotsman & Kazhdan's slides

Once χ is known, the isosurface $\chi(\cdot) = 0.5$ can be extracted

- Using marching cubes, for example



Images from wikipedia.org

3D Reconstruction
Software – Point Cloud Library (PCL)

- C++ open-source library for point cloud processing
- Includes implementations of the above methods

Image from `pointclouds.org`

Preservation of physical artifacts

Image from Levoy et al. 2000

Project Tango

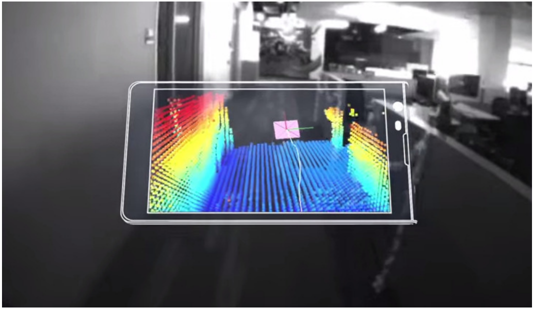
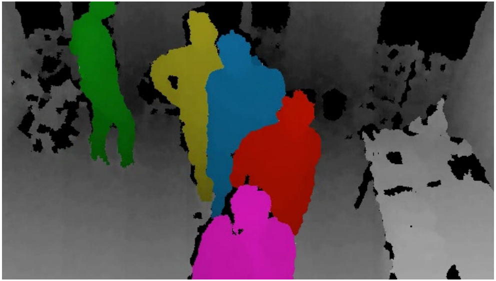


Image from https://www.youtube.com/watch?v=Qe10ExwzCqk

Person Detection

3D data enables reliable person detection

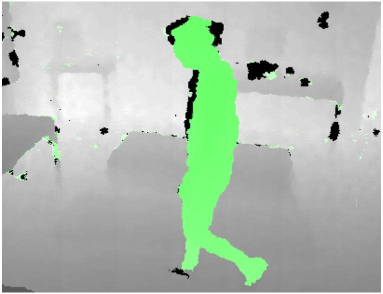
- Robust motion detection
- Distinctive, invariant features



Person Detection
Motion Detection

Reliable motion detection via background subtraction

- Measurements represent object distances
- Not affected by illumination, clothing, shadows



Scene geometry allows for distinctive, invariant features

- Object size, extent, volume, shape, ...

More on object detection later

Person Detection
Applications – Breaking Assistance

https://www.youtube.com/watch?v=oU4XQvxO10k

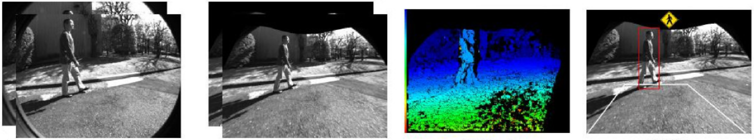


Image from Ryuzo Okada, Toyota

Person Detection
Applications – Interactive Art Installations

Image from `ortlos.com`

Fall detection system developed at CVL

- Uses data from a single Kinect sensor
- Detects falls by tracking the height of persons

https://www.youtube.com/watch?v=p2qlHoxPioM

Kinect Player Pose Estimation

Let's take a look at how this works

Assuming we have already detected the person

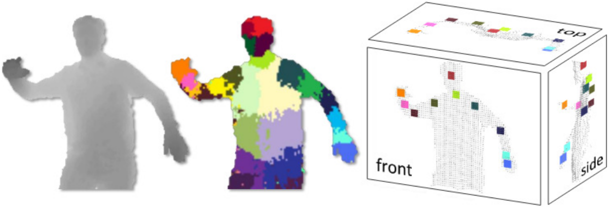


Image from Shotton et al. 2011

Kinect Player Pose Estimation

Steps

Estimate body part of each pixel independently

Perform clustering to obtain joint position proposals

Fit skeleton model to joint proposals

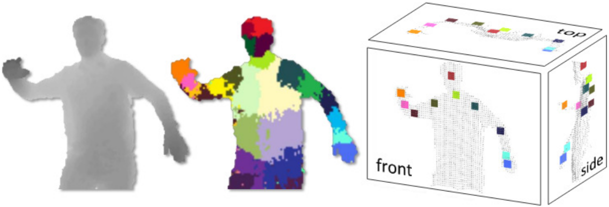


Image from Shotton et al. 2011

For each pixel $\mathbf{x}$ with depth $d(\mathbf{x})$ compute $\Pr(w|\mathbf{x})$

- With w representing the body part, $w \in \{0, \ldots, 30\}$
- Note that this is a discriminative model

Image from Shotton et al. 2011

Classification using simple depth offset features $f_{\boldsymbol{\theta}}$,

$$f_{\boldsymbol{\theta}=(\mathbf{u},\mathbf{v})}(\mathbf{x}) = d\left(\mathbf{x} + \frac{\mathbf{u}}{d(\mathbf{x})}\right) - d\left(\mathbf{x} + \frac{\mathbf{v}}{d(\mathbf{x})}\right)$$

Image adapted from Shotton et al. 2011

Kinect Player Pose Estimation
Pixel Classification

One such feature is weak

But a strong classifier can be built by combining them

Implemented using a **random forest**

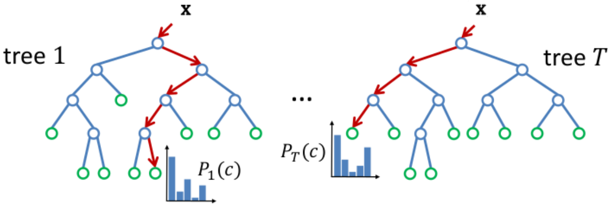


Image adapted from Shotton et al. 2011

Kinect Player Pose Estimation

Pixel Classification – Random Forests

Random forest consists of T randomized decision trees

Each tree t consist of split and leaf nodes

Each split node consists of a feature $f_{\boldsymbol{\theta}}$ and a threshold τ

- $\mathbf{x}$ branches down based on $f_{\boldsymbol{\theta}_k} > \tau_k$
- Until a leaf node is reached, which stores $\mathrm{Pr}_t(w|\mathbf{x})$

Tree trained from training samples $(\mathbf{x}, w)$

- Samples differ between trees
- $\boldsymbol{\theta}_k, \tau_k$ selected randomly (hence random tree)

All trees contribute to the result, $P(w|\mathbf{x}) = \sum_{t=1}^{T} \Pr_t(w|\mathbf{x})$

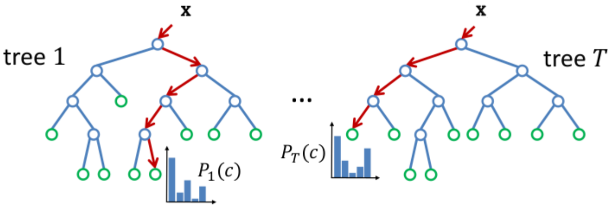


Image adapted from Shotton et al. 2011

Project classified pixels to 3D

Perform clustering for each label w using mean-shift

- https://www.youtube.com/watch?v=kmaQAsotT9s

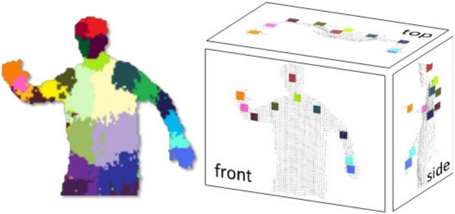


Image adapted from Shotton et al. 2011

Results in n_w joint position proposals per body part w

Goal is to find best joint configuration

Can be accomplished using a constellation model, for example

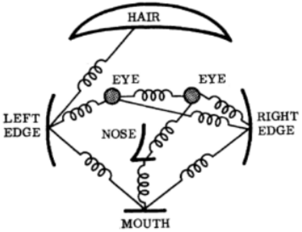


Image from Fischler and Elschlager 1973

Kinect Player Pose Estimation

Results

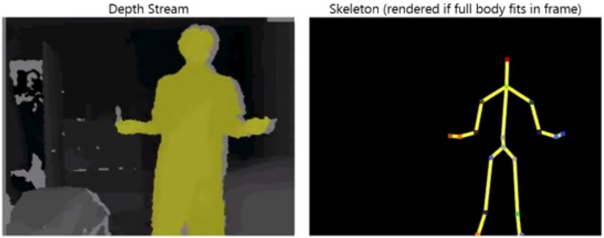


Image from `https://www.youtube.com/watch?v=YTBvjLGDluY`

Kinect SDK

Official SDK for Kinect v1 and v2

Provides access to sensor streams, skeleton data, and more

Available at `http://www.microsoft.com/en-us/kinectforwindows/`

Alternatives for non-windows platforms

- OpenNI2 (`https://github.com/occipital/openni2`)
- libfreenect2 (`https://github.com/OpenKinect/libfreenect2`)

Summary

Knowledge of scene geometry enables powerful CV applications

We have covered a selection

- 3D reconstruction for virtual reality
- Person detection for breaking assistance
- Human pose estimation for gaming

3D Vision Lecture

Interested in 3D vision?

- There is an own VO (183.129) and UE (183.130)

Bibliography I

Aiger, Dror, Niloy J Mitra, and Daniel Cohen-Or (2008). **4-points congruent sets for robust pairwise surface registration**.

Berger, Matthew et al. (2014). **State of the Art in Surface Reconstruction from Point Clouds**.

Curless, Brian and Marc Levoy (1996). **A volumetric method for building complex models from range images**.

Fischler, Martin A and Robert A Elschlager (1973). **The representation and matching of pictorial structures**.

Kazhdan, Michael (2005). **Reconstruction of solid models from oriented point sets**.

Bibliography II

Kazhdan, Michael, Matthew Bolitho, and Hugues Hoppe (2006). **Poisson surface reconstruction**.

Levoy, Marc et al. (2000). **The digital Michelangelo project: 3D scanning of large statues**.

Newcombe, Richard A et al. (2011). **KinectFusion: Real-time dense surface mapping and tracking**.

Shotton, Jamie et al. (2011). **Real-Time Human Pose Recognition in Parts from a Single Depth Image**.