Projects

Capture Project

- Details are on the blog (questions?)
- 3D scanner demo during class today
- You should be starting this week
Projects

Capture Project

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Upcoming Deadlines

- October 10 - Capture project in class presentations
- October 15 - Final project pitches (3 weeks)
Brief Review

Last Class: Motion capture more broadly

Practical systems for capturing motion
- Allow (some) editing of motion
- Can be used as measuring tools

This Class: Motion capture for gaming (and HCI)

[ Minority Report, 2002 ]
Plan for Today’s Class

- Review of some hardware devices for gaming
- Focus on Kinect
  - Structured light for depth estimation
  - Inference of 3D pose
- Discussion and some applications
Game Capture vs. Motion Capture

Technologies as you will see are very similar, but are tweaked for the HCI type of scenario

Usability:
Cost:
Computation:
Quality:
Game Capture vs. Motion Capture

Technologies as you will see are very similar, but are tweaked for the HCI type of scenario

**Usability:** Easy to use, put on and take off

**Cost:**

**Computation:**

**Quality:**
Game Capture vs. Motion Capture

Technologies as you will see are very similar, but are tweaked for the HCI type of scenario

**Usability:** 1 or less hand-held sensors

**Cost:**

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Game Capture vs. Motion Capture

Technologies as you will see are very similar, but are tweaked for the HCI type of scenario

**Usability:** 1 or less hand-held sensors

**Cost:** < $100

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**Quality:**
Game Capture vs. Motion Capture

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**Cost:** < $100

**Computation:** Low (10% of CPU can be spent on sensing)

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Wiimote

- Wireless communication (Bluetooth)

- Sensors
  - Accelerometer for orientation (3 axis)
  - Optical sensor for pointing

- Supports two handed interaction
  - Can use 2 Wiimotes simultaneously

[ Some content taken from Joseph LaViola ]
Wiimote
- Wireless communication (Bluetooth)
- Sensors
  - Accelerometer for orientation (3 axis)
  - Optical sensor for pointing
- Supports two handed interaction
- Can use 2 Wiimotes simultaneously

Simplified version of:

**Inertial Suites**
- Inertial sensors (gyros)
  - Accelerometer: measures acceleration
  - Gyroscope: measures orientation

**Semi-passive**
- Multi-LED IR projectors in the environment emit spatially varying patterns
- Photo-sensitive marker tags decode the signals and estimate their position

[ Some content taken from Joseph LaViola ]
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Can be used by themselves or jointly

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Can be used by themselves or jointly

optical sensor is used for more accurate aiming control

[ Some content taken from Joseph LaViola ]
Optical Sensing with Wiimote

Use triangulation to determine depth
- Distance between imaged LEDs on sensor varies with depth
- Distance between LEDs on the sensor bar fixed
- Angle can be calculated from angle between imaged LEDs

[ Some content taken from Joseph LaViola ]

10 LED lights (5 on each side)
Wiimote Limitations

- Not quite 6 DOFs (orientation + depth)
- Only provides approximate depth
- Limited range (~ 5 meters)
- To triangulate depth requires line of sight to the bar

[ Some content taken from Joseph LaViola ]
Wiimote Limitations

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Wii Motion Plus

- Adds a gyro for additional orientation quality
- Still unable to provide reliable 3D position information
Prototype Systems

Use multiple Wiimotes and map them to motion of a character

[ Shiratori and Hodgins, ACM SIGGRAPH Asia, 2008]
Prototype Systems

Use multiple Wiimotes and map them to motion of a character

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PlayStation Move

- Wireless communication
- Sensors
  - Optical camera tracking (absolute 3D position)
  - 3 axis accelerometer
  - 3 axis gyroscope
  - Magnetometer (helps with drift)
- Can use up to 4 controllers simultaneously

[Some content taken from Joseph LaViola]
PlayStation Move

- Wireless communication

- Sensors
  - Optical camera tracking (absolute 3D position)
  - 3 axis accelerometer
  - 3 axis gyroscope
  - magnetometer (helps with drift)

- Can use up to 4 controllers simultaneously

- PlayStation Eye
  - 640 x 480 (60 Hz)
  - 320 x 240 (120 Hz)

[ Some content taken from Joseph LaViola ]
PlayStation Move

- Wireless communication
- Sensors
  - Optical camera tracking (absolute 3D position)
  - 3 axis accelerometer
  - 3 axis gyroscope
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Simplified version of:

<table>
<thead>
<tr>
<th>Inertial Suites</th>
<th>Active Marker-based Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Inertial sensors (gyros)</td>
<td>- Resolve correspondence by activating one LED marker at a time (very quickly)</td>
</tr>
<tr>
<td>- Accelerometer: measures acceleration</td>
<td>- LEDs can be tuned to be easily picked up by cameras</td>
</tr>
<tr>
<td>- Gyroscope: measures orientation</td>
<td>Weta used for “Rise of the Planet of the Apes”</td>
</tr>
</tbody>
</table>

ILM used for “Van Helsing”

[ Some content taken from Joseph LaViola ]
PlayStation Move: Optical Tracking

44mm sphere serves as an active LED marker (with controlled color)

Controllable color simplifies

- Correspondences (immediately know id of controller)
- Segmentation of the marker from background (remember active optical markers)

[ Some content taken from Joseph LaViola ]
PlayStation Move: Optical Tracking

44mm sphere serves as an active LED marker (with controlled color)

Under perspective projection spherical marker images as an ellipsoid

[ Some content taken from Joseph LaViola ]
PlayStation Move: Optical Tracking

44mm sphere serves as an active LED marker (with controlled color)

Under perspective projection spherical marker images as an ellipsoid

- Detect marker pixels
- Fit ellipsoid to them
- Ellipsoid + calibration = 3D position
  - Ray through centroid gives a line in space
  - Size and orientation of the ellipsoid give depth along the line

[ Some content taken from Joseph LaViola ]
Playstation Move Limitations

- 6 DOFs (orientation + position in 3D)
- Limited range (~ 5 meters)
- Requires line of sight to the camera
Kinect

Two key contributions:
- Inexpensive and accurate depth camera / sensor
- 3D pose estimation

Color Image  Depth Image  Body Part Segmentation  3D Joint Estimation
Two key contributions:

- Inexpensive and accurate depth camera / sensor
- 3D pose estimation
Structure of the Sensor

[ Src: Kinect for Windows SDK ]
Depth Map Construction

Kinect combines structured light with two other computer vision techniques: depth from focus and depth from stereo
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( Everything I will tell you is a speculation, taken from PrimeSense patent and notes from John MacCormick, Microsoft )
Depth Map Construction

Kinect combines structured light with two other computer vision techniques: depth from focus and depth from stereo.

(Everything I will tell you is a speculation, taken from PrimeSense patent and notes from John MacCormick, Microsoft.)

Structured light has a long history in vision:

Cleverly projected pattern of light observed from the camera can tell us a lot about 3D structure of the scene.

[ Zhang et al, 3DPVT, 2002 ]

[ Slide after John MacCormick]
Example: Line as a “the structure”
Example: Line as a “the structure”

Project laser stripe onto object
Example: Line as a “the structure”

- Project laser stripe onto object

[ Slide from S. Narasimhan ]

Monday, September 24, 12
Example: Line as a “the structure”

Depth from ray-plane triangulation:
- Intersect camera ray with light plane

[ Slide from S. Narasimhan ]
Example: Line as a “the structure”

Depth from ray-plane triangulation:
- Intersect camera ray with light plane

Accurate but slow
Kinect’s Structured Light

Speckle patterns using infrared light

[ Shpunt et al., PrimeSense patent application US 2008/0106746 ]
Dealing with Correspondences

Correspondences can be computed based on closest distance between intersection of 3D lines (from camera and laser)
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Correspondences can be computed based on closest distance between intersection of 3D lines (from camera and laser)

Lower density of speckles and/or uniqueness of speckles improves correspondence
Depth From Focus

- What is in focus depends on the depth
- For a given lens there is a nominal depth where everything is in focus, otherwise object will be out of focus

[ Slide after John MacCormick]
Depth From Focus

- What is in focus depends on the depth
- For a given lens there is a nominal depth where everything is in focus, otherwise object will be out of focus
- Kinect improves the accuracy of traditional depth from focus
- Kinect uses a spatial “astigmatic” lens with different focal length in x and y dimensions
- A projected circle becomes an ellipse whose orientation depends on depth

[ Freedman et al., PrimeSense patent application US 2010/0290698 ]

[ Slide after John MacCormick]
Depth From Focus

Speckles are the “circles”

[ Shpunt et al., PrimeSense patent application US 2008/0106746 ]

[ Slide after John MacCormick]
Depth From Stereo

- Looking at the scene from 2 different angles, pixels that correspond to closer objects move more than pixels that correspond to further objects.

This is how many depth cameras work.

Depth From Stereo

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  This is how many depth cameras work.

- Kinect analyzes shift of the speckle pattern by projecting from one location and observing from another.

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Color Image  Depth Image  Body Part Segmentation  3D Joint Estimation
Kinect

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Color Image

Depth Image

Body Part Segmentation

3D Joint Estimation
Kinect

Two key contributions

- Inexpensive and accurate depth camera / sensor
- 3D Pose estimation

Again, correspondences are difficult
3D Pose Estimation
(without correspondences)

- Generate synthetic examples of “images” from MoCap
- This creates a database of image-pose pairs
- Learn a function that takes image features as input and outputs 3D pose

[Inferring body pose without tracking body parts, Rosales & Sclaroff, CVPR, 2000]
Simplest Regression-based Method

[Shakhnarovich, Viola, Darrell, ICCV'03]
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[Shahnavaz, Viola, Darrell, ICCV'03]

**Given:** large database of image-pose pairs
Simplest Regression-based Method

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**Pose inference:** trivial using a NN approach
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**Given:** large database of image-pose pairs

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Nearest Neighbor Regression

[ Shakhnarovich, Viola, Darrell, ICCV’03]

- Speeding up the NN lookup using hashing functions
Nearest Neighbor Regression

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- Better results are obtained by weighted average of k- Nearest Neighbors

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Nearest Neighbor Regression

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[ Shakhnarovich, Viola, Darrell, ICCV’03]
Learn a functional mapping from features to pose (e.g. Linear Regression: $x = g(y) = Ay + b$)

feature space $\rightarrow$ pose $\rightarrow$ pose space

Agarwal, Triggs, CVPR’04
Imaging Ambiguities
Imaging Ambiguities

[ Agarwal and Triggs, CVPR’05 ]
Imaging Ambiguities

[ Agarwal and Triggs, CVPR’05 ]
Mixture of Experts
[ Sminchisescu et al PAMI’07, Bo et al CVPR’08 ]

Muti-modal probabilistic functions

feature space

\[ f(I) \]

pose space

\[ y \in \mathcal{R}^{300} \]

\[ x \in \mathcal{R}^{40} \]

\[ \text{pose} = g_1 \left( \text{features} \right) \]

\[ \text{pose} = g_2 \left( \text{features} \right) \]
Mixture of Experts

[ Sminchisescu et al PAMI’07, Bo et al CVPR’08 ]
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An Interesting Application

[ Ren, Shakhnarovich, Hodgins, Pfister, Viola, ACM SIGGRAPH, 2004 ]

In this case multiple (3) cameras are used, but using similar regression-based (correspondence free) approach
An Interesting Application

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Subject 1
Music: Swingtime

In this case multiple (3) cameras are used, but using similar regression-based (correspondence free) approach
Kinect

Depth image:

- Resolves ambiguities in pose
- Make it easy to segment person from background

Color Image  Depth Image  Body Part Segmentation  3D Joint Estimation
Step 1: Create a synthetic dataset

- 15 different body types
- About 100,000 poses
- Render depth image-pose pairs

[ Shotton, Fitzgibbon, Cook, Sharp, Finocchio, Moore, Kipman, Blake, CVPR’11 ]
Step 2: Learn mapping to body parts

Train a randomized decision forests
Step 2: Learn mapping to body parts

Train a randomized decision forests

It's like a sophisticated game of 20 questions (decision tree)

[ Slide after John MacCormick]
Step 2: Learn mapping to body parts

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Should you take an umbrella?

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Questions Kinect Asks

How does the (normalized) depth at the given pixel compares to the (normalized) depth at a pixel with a given offset.

[Shotton, Fitzgibbon, Cook, Sharp, Finocchio, Moore, Kipman, Blake, CVPR’11]

[Slide after John MacCormick]
Questions Kinect Asks

How does the (normalized) depth at the given pixel compares to the (normalized) depth at a pixel with a given offset

Note: this is only a form of the question, there are millions of these types of questions that can be asked depending on the parameters (e.g., offset, comparisons)

[Shotton, Fitzgibbon, Cook, Sharp, Finocchio, Moore, Kipman, Blake, CVPR'11]
Learning a Decision Tree

- Need to choose a sequence of questions to ask
- Which question is most useful to ask next?
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e.g. for taking an umbrella is it more useful to ask “is it raining?” or “is it cloudy?”
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Learning a Decision Tree

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  e.g. for taking an umbrella is it more useful to ask “is it raining?” or “is it cloudy?” Why?

- Mathematically this takes the form of information gain (which is derived from entropy)

  (I am not going to go through the details)

[Slide after John MacCormick]
Randomized Decision Forest

Randomized
- Too many possible questions, so use a different random sub-set of 2,000 each time

Forest
- Instead of training one decision tree, train many
- Use results from all to make a decision

[ Slide after John MacCormick]
Kinect

Depth image:

- Resolves ambiguities in pose
- Make it easy to segment person from background

Color Image

Depth Image

Body Part Segmentation

3D Joint Estimation
Body Parts to Skeleton

Find centroids of parts
Use robust (and fast) algorithm -- Mean Shift
Kinect

Is body segmentation really needed?

Color Image  Depth Image  Body Part Segmentation  3D Joint Estimation
Figure 5. Inferred joint positions. (Left) Each example shows an input depth image with color-coded ground truth joint positions overlaid, and then inferred joint positions from front, right, and top views. The size of the boxes indicates the inferred confidence. Our algorithm achieves accurate prediction of internal body joints for varied body sizes, poses, and clothing. The middle row shows accurate prediction of even occluded joints, and the bottom row shows some failure cases. (Right) Example inference results on flattened 2D silhouettes. Ground truth joint positions are plotted as crosses and the highest scoring hypothesis for each joint appears as a color-coded circle, with size indicating confidence. Despite substantially more visual ambiguity, our algorithm is able to predict many joint positions accurately.

Figure 6. Results on the MSRC-5000 test set compared to [18].
(a) Mean average precision versus total number of training images. (b) Average precision on each of the 16 test body joints. Our algorithm achieves substantially better accuracy with fewer training images.

You can do better regressing directly to 3D joints

Color Image
Depth Image
3D Joint Estimation
Kinect

Done using similar regression forest as before

You can do better regressing directly to 3D joints
Nearest Neighbor Regression

In practice, similar to k Nearest Neighbor, except much faster

[Shakhnarovich, Viola, Darrell, ICCV'03]
Nearest Neighbor Regression

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Discussion
Closed Universe

All of these are input devices

- Most games need few discrete controls
- Game designers are typically able to define controls that are SO different that any noise in location/skeleton will not really effect performance
Designing Around Limitations

- Game designers are really good about designing around limitations of input devices

[ Raptis, Kirovski, Hoppes, SCA, 2011 ]
Designing Around Limitations

- Game designers are really good about designing around limitations of input devices

[ Raptis, Kirovski, Hoppes, SCA, 2011 ]
- Even for very complex game interfaces, at any given point of the game only few gestures are possible
- Avatar can ask you to perform any motion, but once asked, the system only cares if you perform *that* motion
Leap Motion