

3D User Interfaces for Games and Virtual Reality

Lecture #4: Video Game Motion Controllers

Spring 2019

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3D Spatial Input Hardware – The Past



Intersense IS-900



Polhemus Patriot



3rd Tech Hi Ball

These Devices cost thousands of Dollars!!

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3D Spatial Input Hardware – Today



PlayStation Move



Nintendo Wiimote



Microsoft Kinect



HTC Vive Controllers

These Devices cost hundreds of Dollars!!

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Lecture Outline

- Discuss video game motion controller hardware characteristics
 - Nintendo Wiimote
 - Microsoft Kinect
 - PlayStation Move
- Case Studies

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Devices

The Wiimote Device

- Wiimote features
 - uses Bluetooth for communication
 - senses acceleration along 3 axes
 - optical sensor for pointing (uses sensor bar)
 - provides audio and rumble feedback
 - standard buttons and trigger
 - uses 2 AA batteries
- Supports two handed interaction
 - can use 2 Wiimotes simultaneously
- Easily expandable



Wiimote Attachments



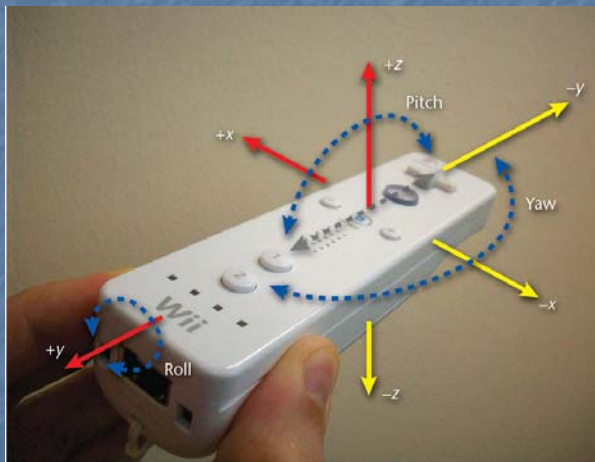
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The Wiimote – Coordinates

Wiimote Coordinates



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The Wiimote – Optical Data

- Data from optical sensor
 - uses sensor bar
 - 10 LED lights (5 of each side)
 - accurate up to 5 meters
 - triangulation to determine depth
 - distance between two points on image sensor (variable)
 - distance between LEDs on sensor bar (fixed)
 - roll (with respect to ground) angle can be calculated from angle of two image sensor points
- Advantages
 - provides a pointing tool
 - gives approximate depth
- Disadvantages
 - line of sight, infrared light problems
 - only constrained rotation understanding

Sensor Bar



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The Wiimote – Motion Data

- Data from 3-axis accelerometer
 - senses instantaneous acceleration on device (i.e., force) along each axis
 - arbitrary units (+/- 3g)
 - always sensing gravity
 - at rest acceleration is g (upward)
 - freefall acceleration is 0
 - finding position and orientation
 - at rest – roll and pitch can be calculated easily
 - in motion – math gets more complex
 - error accumulation causes problems
 - often not needed – gestures sufficient
- Advantages
 - easily detect course motions
 - mimic many natural actions
- Disadvantages
 - ambiguity issues
 - player cheating
 - not precise (not a 6 DOF tracker)



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The Wii Motion Plus

- Current Wiimote device
 - gives user a lot of useful data
 - not perfect
 - ambiguities
 - poor range
 - constrained input
 - Wii Motion Plus
 - moving toward better device
 - finer control
 - uses dual axis “tuning fork” angular rate gyroscope
 - true linear motion and orientation



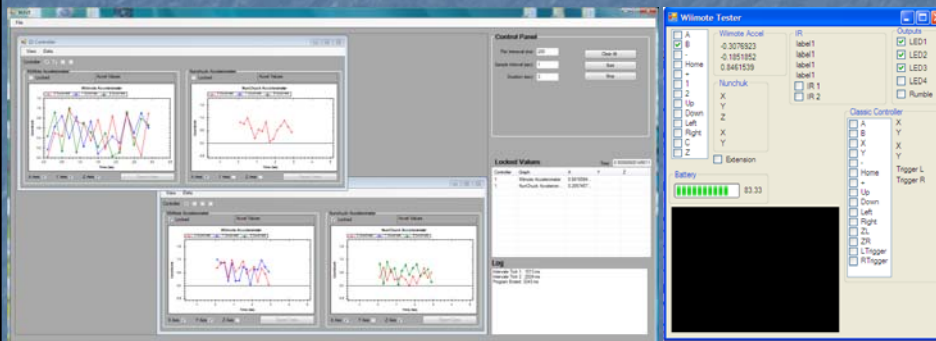
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Visualizing Wiimote Data

- Important to see data to understand device



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Microsoft Kinect

- Kinect features
 - RGB camera
 - depth sensors
 - multi-array mic
 - motorized tilt
 - connects via USB
- Supports controllerless interface
- Full body tracking



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Kinect – Hardware Details

- RGB Camera
 - 640 x 480 resolution at 30Hz
- Depth Sensor
 - complimentary metal-oxide semiconductor (CMOS) sensor (30 Hz)
 - infrared laser projector
 - 850mm to 4000mm distance range
- Multi-array mic
 - set of four microphones
 - multi-channel echo cancellation
 - sound position tracing
- Motorized tilt
 - 27° up or down



www.hardwareSphere.com

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Kinect – Extracting 3D Depth

- Infrared laser projector emits known dot pattern
- CMOS sensor reads depth of all pixels
 - 2D array of active pixel sensors
 - photo detector
 - active amplifier
- Finds location of dots
- Computes depth information using stereo triangulation
 - normally needs two cameras
 - laser projector acts as second camera
- Depth image generation



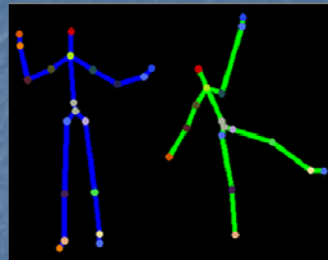
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Kinect – Skeleton Tracking

- Combines depth information with human body kinematics
 - 20 joint positions
- Object recognition approach
 - per pixel classification
 - decision forests (GPU)
 - millions of training samples
- See Shotton et al. (CVPR 2011)



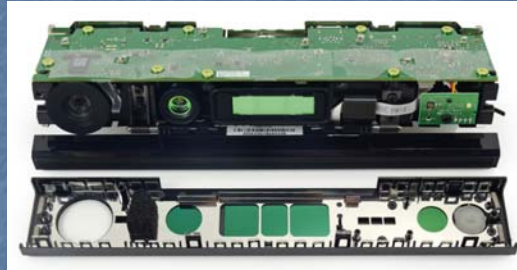
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Kinect 2

- RGB Camera
 - HD resolution
- Depth Sensor
 - time of flight
- microphone array
- ToF – illuminate it with a beam of pulsed light and calculate time it takes for the light to be detected on an imaging device



http://www.aud.ucla.edu/programs/m_arch_ii_degree_1/studios/2013_2014/gehry/?p=786

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Kinect 2 – Other Differences

- Greater accuracy
 - three times the fidelity over Kinect
- Can track without visible light using an active IR sensor
- Has a 60% wider field of view
 - detect a user up to 3 feet from the sensor compared to six feet for the Kinect
 - track up to 6 skeletons at once
- Detect a player's [heart rate](#) and facial expressions,
- Position and orientation of 25 individual joints (including thumbs),
- Weight put on each limb and speed of player movements



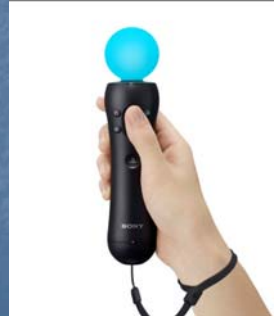
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PlayStation Move

- Consists of
 - Playstation Eye
 - 1 to 4 Motion controllers
- Features
 - combines camera tracking with motion sensing
 - 6 DOF tracking (position and orientation)
 - several buttons on front of device
 - analog T button on back of device
 - vibration feedback
 - wireless



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PlayStation Move – Hardware

- PlayStation Eye
 - 640 x 480 (60Hz)
 - 320 x 240 (120Hz)
 - microphone array
- Move Controller
 - 3 axis accelerometer
 - 3 axis angular rate gyro
 - magnetometer (helps to calibrate and correct for drift)
 - 44mm diameter sphere with RGB LED
 - used for position recovery
 - invariant to rotation
 - own light source
 - color ensures visual uniqueness



www.hardwaresphere.com

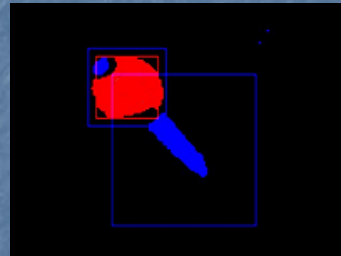
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PlayStation Move – 6 DOF Tracking

- Image Analysis
 - find sphere in image
 - segmentation
 - label every pixel being tracked
 - saturated colors more robust
 - pose recovery
 - convert 2D image to 3D pose
 - robust for certain shapes (e.g., sphere)
 - fit model to sphere projection
 - size and location used as starting point
 - 2D perspective projection of sphere is ellipse
 - given focal length and size of sphere, 3D position possible directly from 2D ellipse parameters



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PlayStation Move – 6 DOF Tracking

- Sensor Fusion
 - combines results from image analysis with inertial sensors (Unscented Kalman Filter)
 - contributions
 - camera – absolute 3D position
 - accelerometer
 - pitch and roll angles (when controller is stationary)
 - controller acceleration (when orientation is known)
 - reduce noise in 3D position and determine linear velocity
 - gyroscope
 - angular velocity to 3D rotation
 - angular acceleration

Initial state

$$\hat{x}_0 = \hat{x}_0^c$$

$$P_0 = \hat{P}_0^c + \hat{P}_0^i - \hat{x}_0^c \hat{x}_0^{i^T} - \hat{x}_0^{i^T} \hat{x}_0^c$$

$$\hat{x}_0^c = \begin{bmatrix} x \\ y \\ z \\ \alpha \\ \beta \\ \gamma \end{bmatrix}$$

$$\hat{P}_0^c = \begin{bmatrix} P_{xx} & 0 & 0 & 0 & 0 & 0 \\ 0 & P_{yy} & 0 & 0 & 0 & 0 \\ 0 & 0 & P_{zz} & 0 & 0 & 0 \\ 0 & 0 & 0 & P_{\alpha\alpha} & 0 & 0 \\ 0 & 0 & 0 & 0 & P_{\beta\beta} & 0 \\ 0 & 0 & 0 & 0 & 0 & P_{\gamma\gamma} \end{bmatrix}$$

For $k \in \{1, \dots, n\}$,

Generate sigma points

$$\hat{x}_{k-1}^s = \left[\hat{x}_{k-1}^c \quad \hat{x}_{k-1}^i \quad \pm \sqrt{(L+1)P_{k-1}} \right]$$

Time update

$$\hat{x}_{k|k-1}^c = F_k^c \hat{x}_{k-1}^c$$

$$\hat{x}_{k|k-1}^i = \hat{x}_{k-1}^i$$

$$P_{k|k-1}^c = F_k^c P_{k-1}^c F_k^{c^T} + Q_k^c$$

$$P_{k|k-1}^i = P_{k-1}^i$$

$$P_{k|k-1} = \begin{bmatrix} P_{k|k-1}^c & 0 \\ 0 & P_{k|k-1}^i \end{bmatrix}$$

Measurement update equations

$$P_{k|k}^c = \sum_{j=0}^L w_j^c (Z_k^c - \hat{Z}_k^c)^2 P_{k|k-1}^c - \hat{Z}_k^c \hat{Z}_k^{c^T} + S_k^c$$

$$P_{k|k}^i = \sum_{j=0}^L w_j^i (Z_k^i - \hat{Z}_k^i)^2 P_{k|k-1}^i - \hat{Z}_k^i \hat{Z}_k^{i^T} + S_k^i$$

$$K_k = P_{k|k}^c P_{k|k}^{-1}$$

$$\hat{x}_k = \hat{x}_{k|k-1} + K_k (Z_k - \hat{Z}_k)$$

$$P_k = P_{k|k-1} - K_k P_{k|k-1} K_k^T$$

where, $\alpha^c = [\alpha^x \ \alpha^y \ \alpha^z]^T$, $\alpha^i = [\alpha^p \ \alpha^r \ \alpha^y]^T$. Assumptions: w_j^c parameters, Z_k^c direction of camera's state, $P_{k|k-1}^c$ covariance matrix, $P_{k|k-1}^i$ covariance matrix, K_k gain matrix as calculated in Eqn. 16.

Algorithm 3.1: Unscented Kalman Filter (UKF) equations

www.cslu.org.edu/nsel/ukf/node6.html

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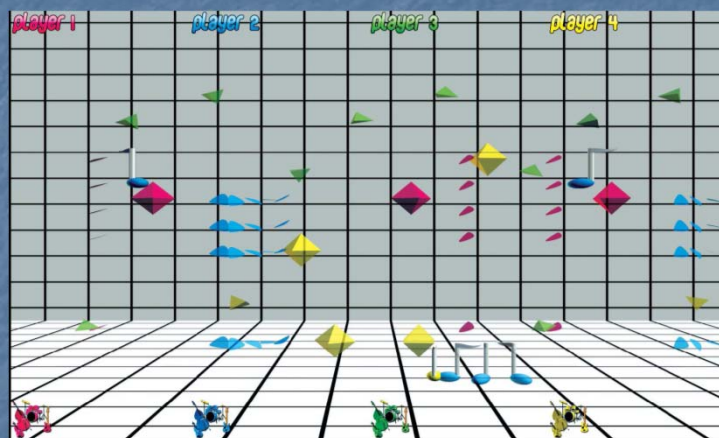
Case Studies

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One Man Band



Bott et al., 2009

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Real Dance



Charbonneau et al., 2009

Charbonneau et al., 2010

Charbonneau et al., 2011

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Football



Williamson et al., 2010



Kinect Football by Andrew Devine

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RealEdge – FPS



Williamson et al., 2011

Robots



Pfeil et al., 2013

Conclusions – Which to Choose?

- Wiimote
- Positives
 - cost ~ \$40
 - buttons
 - something to hold in hand
- Negatives
 - not true 6 DOF
 - challenging to program
 - reasonable accuracy
 - no company support



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Conclusions – Which to Choose?

- Microsoft Kinect
- Positives
 - cost ~ \$130
 - full body tracking
 - joint position
 - joint orientation (Kinect 2)
 - multimodal input
 - good SDK and support
- Negatives
 - no buttons (temporal segmentation problem)
 - more data to process
 - not really designed with physical props in mind
 - latency issues (gesture recognition)



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Conclusions – Which to Choose?

- PlayStation Move
- Positives
 - accurate and fast 6 DOF tracking
 - buttons
 - multimodal input
 - good SDK and support
- Negatives
 - cost ~ \$400 to \$500
 - requires PS3 (positive as well)
 - does not track full body (more restrictive)



Next Class

- Human Factors
- Readings
 - Siggraph 2010, 2011 course notes on 3D UI and Video Game Hardware