

3D User Interfaces for Games and Virtual Reality

Lecture #3: Video Game Motion Controllers
Spring 2024

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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



Meta Quest 2



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



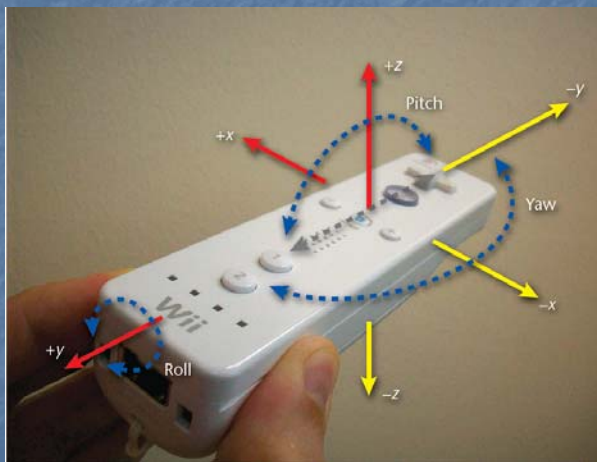
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The Wiimote – Coordinates

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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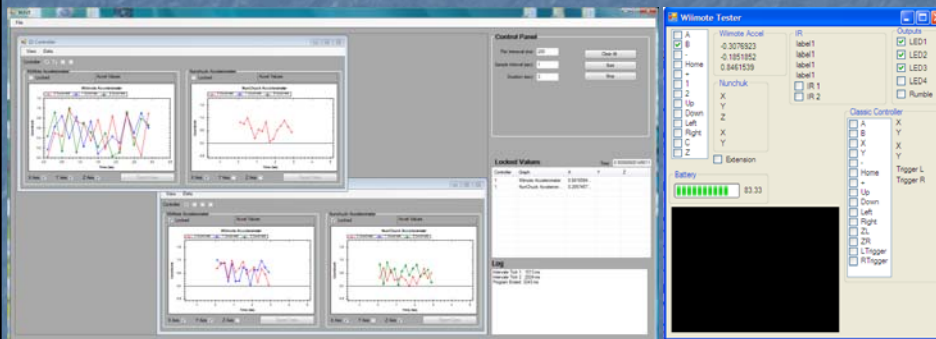
The Wii Motion Plus

- 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



Visualizing Wiimote Data

- Important to see data to understand device



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



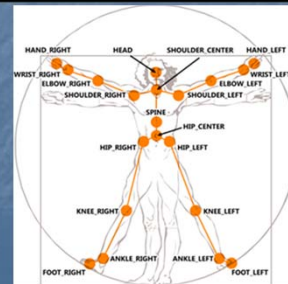
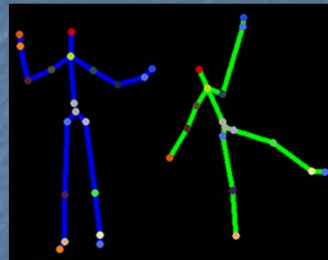
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Kinect – Skeleton Tracking

- 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)



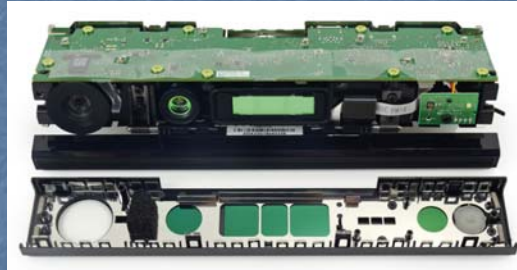
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Kinect 2

- 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



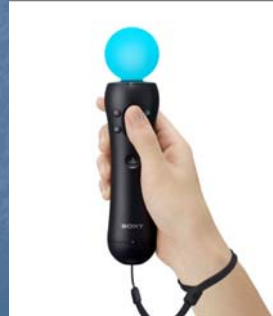
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PlayStation Move

- 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

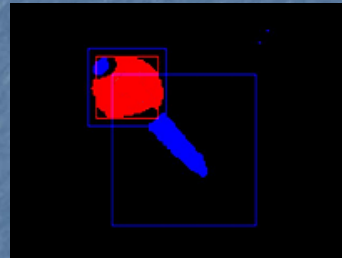
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PlayStation Move – 6 DOF Tracking

- 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



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

Initialize with:

$$\hat{x}_0 = E[x_0]$$

$$P_0 = E[(x_0 - \hat{x}_0)(x_0 - \hat{x}_0)^T]$$

$$\hat{x}_0^c = E[x^c] = [\hat{x}_0^c \ 0 \ 0]^T$$

$$P_0^c = E[(x_0^c - \hat{x}_0^c)(x_0^c - \hat{x}_0^c)^T] = \begin{bmatrix} P_x & 0 & 0 \\ 0 & P_\omega & 0 \\ 0 & 0 & P_\alpha \end{bmatrix}$$

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

Calculate sigma points:

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

Time update:

$$X_{k|k-1}^s = F[X_{k-1}^s, X_{k-1}^s]$$

$$\hat{x}_k^- = \sum_{i=0}^{2L} W_i^{(t)} X_{k|k-1}^s$$

$$P_k^- = \sum_{i=0}^{2L} W_i^{(t)} [X_{k|k-1}^s - \hat{x}_k^-][X_{k|k-1}^s - \hat{x}_k^-]^T$$

$$Y_{k|k-1}^s = H[X_{k|k-1}^s, X_{k-1}^s]$$

$$\hat{y}_k^- = \sum_{i=0}^{2L} W_i^{(t)} Y_{k|k-1}^s$$

Measurement update equations:

$$P_{y_k|y_k} = \sum_{i=0}^{2L} W_i^{(t)} [Y_{k|k-1}^s - \hat{y}_k^-][Y_{k|k-1}^s - \hat{y}_k^-]^T$$

$$P_{x_k|y_k} = \sum_{i=0}^{2L} W_i^{(t)} [X_{k|k-1}^s - \hat{x}_k^-][Y_{k|k-1}^s - \hat{y}_k^-]^T$$

$$K = P_{x_k|y_k} P_{y_k|y_k}^{-1}$$

$$\hat{x}_k = \hat{x}_k^- + K(Y_k - \hat{y}_k^-)$$

$$P_k = P_k^- - K P_{y_k|y_k} K^T$$

where, $x^a = [x^T \ v^T \ n^T]^T$, $X^a = [(X^a)^T \ (X^a)^T \ (X^a)^T]^T$, λ =composite scaling parameter, L =dimension of augmented state, P_x =process noise cov., P_ω =measurement noise cov., W_i =weights as calculated in Eqn. 15.

Algorithm 3.1: Unscented Kalman Filter (UKF) equations
www.cslu.ogi.edu/nsel/ukf/node6.html

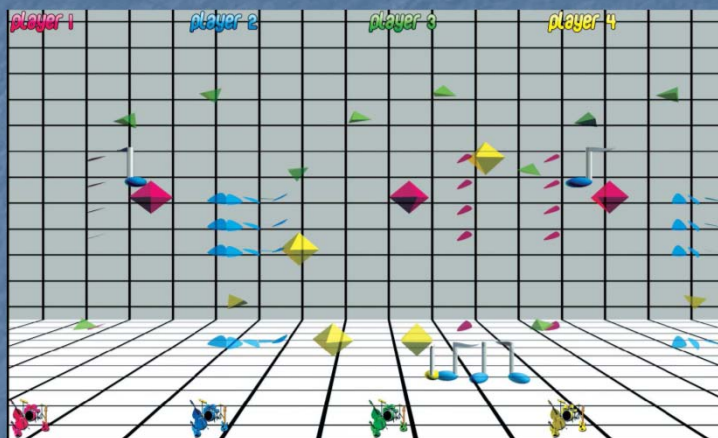
Case Studies

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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

Football



Williamson et al., 2010



Kinect Football by Andrew Devine

RealEdge – FPS



Williamson et al., 2011

Robots



Pfeil et al., 2013

Conclusions – Which to Choose?

- Wiimote
- Positives
 - 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
 - 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
 - requires PS3 (positive as well)
 - does not track full body (more restrictive)



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Next Class

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

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