

# 3D User Interfaces for Games and Virtual Reality

Lecture #3: Video Game Motion Controllers

Spring 2025

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## 3D Spatial Input Hardware – The Past



Intersense IS-900



Polhemus Patriot



3<sup>rd</sup> 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



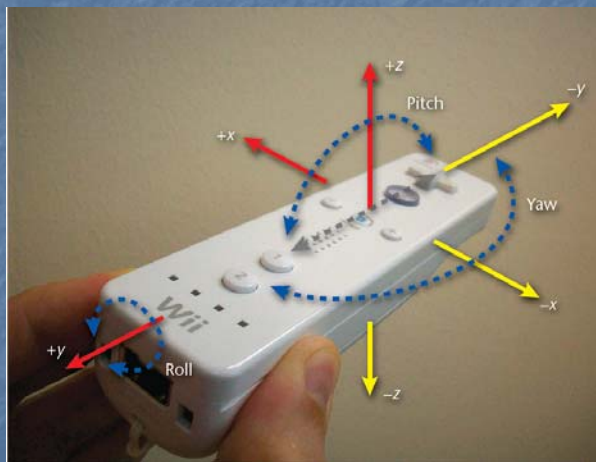
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# The Wiimote – Coordinates

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



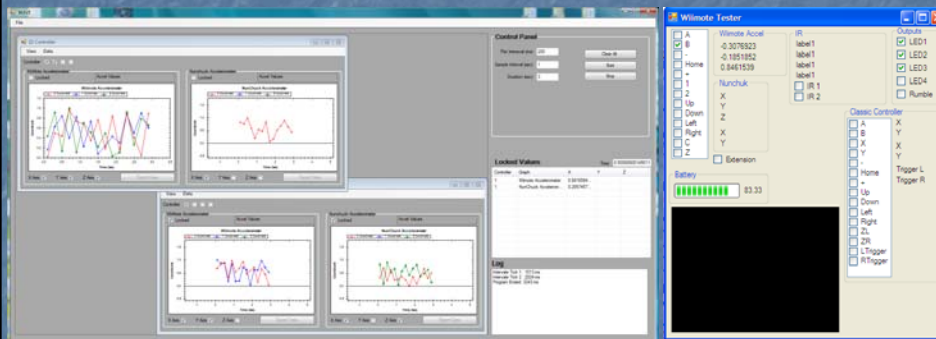
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# Visualizing Wiimote Data

- 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



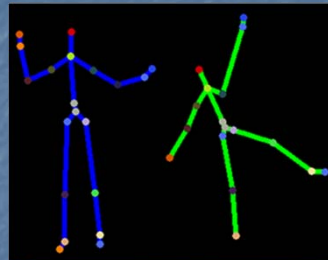
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# Kinect – Skeleton Tracking

- 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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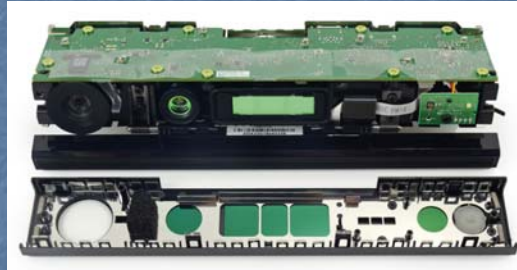
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# Kinect 2

- 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](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



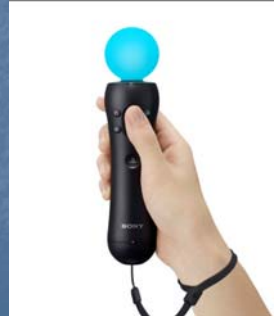
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# PlayStation Move

- 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](http://www.hardwaresphere.com)

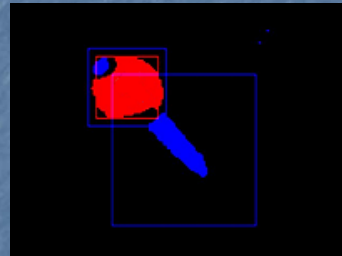
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# PlayStation Move – 6 DOF Tracking

- 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

Initialize with:

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

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

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

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

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:

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

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

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

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

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

Measurement update equations:

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

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

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

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

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

where,  $x^a = [x^T \ v^T \ n^T]^T$ ,  $X^a = [(X^a)^T \ (X^a)^T \ (X^a)^T]^T$ ,  $\lambda$ =composite scaling parameter,  $L$ =dimension of augmented state,  $P_x$ =process noise cov.,  $P_a$ =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](http://www.cslu.ogi.edu/nsel/ukf/node6.html)

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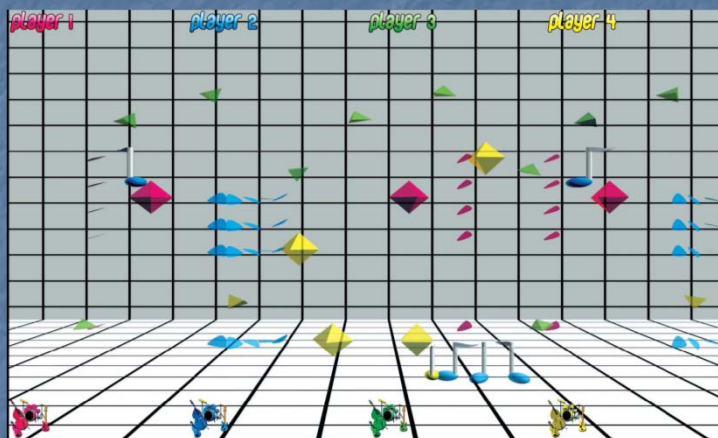
# Case Studies

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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
  - 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

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

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