3D User Interfaces for Games and Virtual Reality

Lecture #4: Video Game Motion Controllers

Spring 2021

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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!!

3D Spatial Input Hardware – Today

PlayStation Move

Nintendo Wiimote

Microsoft Kinect

HTC Vive Controllers

These Devices cost hundreds of Dollars!!

Lecture Outline

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

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

Nunchuk

Steering Wheel

Zapper

Wii Helm

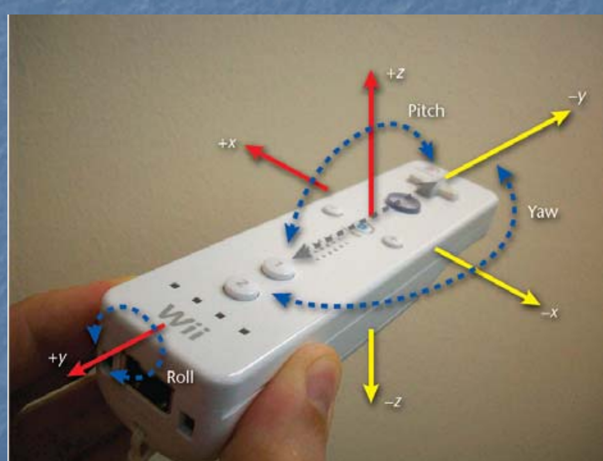
Boxing Gloves

Sports Pack

Fishing Reel

The Wiimote – Coordinates

Wiimote Coordinates



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

The Wiimote – Motion Data

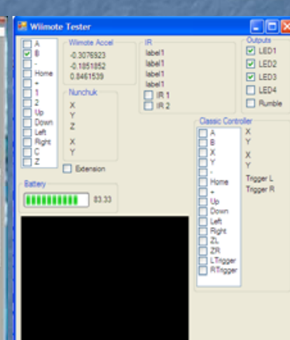
- Data from 3-axis accelerometer
  - senses instantaneous acceleration on device (i.e., force) along each axis
  - arbitrary units (+/- 3g)
  - always sensing gravity
    - at rest acceleration is g (upward)
    - freefall acceleration is 0
  - finding position and orientation
    - at rest – roll and 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)

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

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^{o} up or down

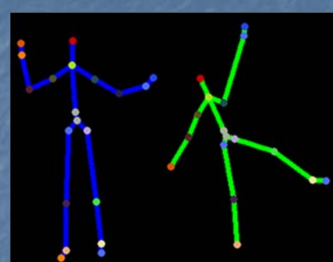
www.hardwaresphere.com

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

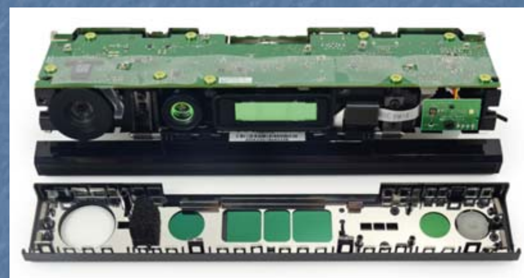
Kinect – Skeleton Tracking

- 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)



Kinect 2

- RGB Camera
  - HD resolution
- Depth Sensor
  - time of flight
- microphone array



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

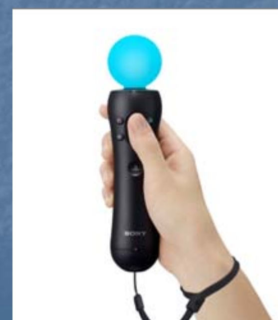
- ToF – illuminate it with a beam of pulsed light and calculate time it takes for the light to be detected on an imaging device

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

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



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

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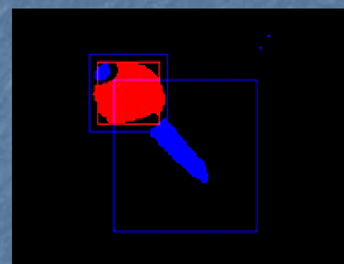
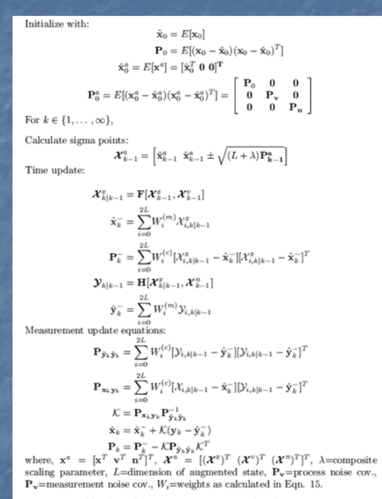
PlayStation Move – 6 DOF Tracking

- 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:

$$\hat{\mathbf{x}}_0 = E[\mathbf{x}_0]$$
$$\mathbf{P}_0 = E[(\mathbf{x}_0 - \hat{\mathbf{x}}_0)(\mathbf{x}_0 - \hat{\mathbf{x}}_0)^T]$$
$$\hat{\mathbf{x}}_0^a = E[\mathbf{x}^a] = [\hat{\mathbf{x}}_0^T\ \mathbf{0}\ \mathbf{0}]^{\mathbf{T}}$$
$$\mathbf{P}_0^a = E[(\mathbf{x}_0^a - \hat{\mathbf{x}}_0^a)(\mathbf{x}_0^a - \hat{\mathbf{x}}_0^a)^T] = \begin{bmatrix} \mathbf{P}_0 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{P_v} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{P_n} \end{bmatrix}$$

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

Calculate sigma points:

$$\boldsymbol{\mathcal{X}}_{k-1}^a = \left[\hat{\mathbf{x}}_{k-1}^a\ \ \hat{\mathbf{x}}_{k-1}^a \pm \sqrt{(L+\lambda)\mathbf{P}_{\mathbf{k-1}}^{\mathbf{a}}}\right]$$

Time update:

$$\boldsymbol{\mathcal{X}}_{k|k-1}^x = \mathbf{F}[\boldsymbol{\mathcal{X}}_{k-1}^x, \boldsymbol{\mathcal{X}}_{k-1}^v]$$
$$\hat{\mathbf{x}}_k^- = \sum_{i=0}^{2L} W_i^{(m)} \mathcal{X}_{i,k|k-1}^x$$
$$\mathbf{P}_k^- = \sum_{i=0}^{2L} W_i^{(c)} [\mathcal{X}_{i,k|k-1}^x - \hat{\mathbf{x}}_k^-][\mathcal{X}_{i,k|k-1}^x - \hat{\mathbf{x}}_k^-]^T$$
$$\boldsymbol{\mathcal{Y}}_{k|k-1} = \mathbf{H}[\boldsymbol{\mathcal{X}}_{k|k-1}^x, \boldsymbol{\mathcal{X}}_{k-1}^n]$$
$$\hat{\mathbf{y}}_k^- = \sum_{i=0}^{2L} W_i^{(m)} \mathcal{Y}_{i,k|k-1}$$

Measurement update equations:

$$\mathbf{P}_{\tilde{\mathbf{y}}_k \tilde{\mathbf{y}}_k} = \sum_{i=0}^{2L} W_i^{(c)} [\mathcal{Y}_{i,k|k-1} - \hat{\mathbf{y}}_k^-][\mathcal{Y}_{i,k|k-1} - \hat{\mathbf{y}}_k^-]^T$$
$$\mathbf{P}_{\mathbf{x}_k \mathbf{y}_k} = \sum_{i=0}^{2L} W_i^{(c)} [\mathcal{X}_{i,k|k-1} - \hat{\mathbf{x}}_k^-][\mathcal{Y}_{i,k|k-1} - \hat{\mathbf{y}}_k^-]^T$$
$$\mathcal{K} = \mathbf{P}_{\mathbf{x}_k \mathbf{y}_k} \mathbf{P}_{\tilde{\mathbf{y}}_k \tilde{\mathbf{y}}_k}^{-1}$$
$$\hat{\mathbf{x}}_k = \hat{\mathbf{x}}_k^- + \mathcal{K}(\mathbf{y}_k - \hat{\mathbf{y}}_k^-)$$
$$\mathbf{P}_k = \mathbf{P}_k^- - \mathcal{K} \mathbf{P}_{\tilde{\mathbf{y}}_k \tilde{\mathbf{y}}_k} \mathcal{K}^T$$

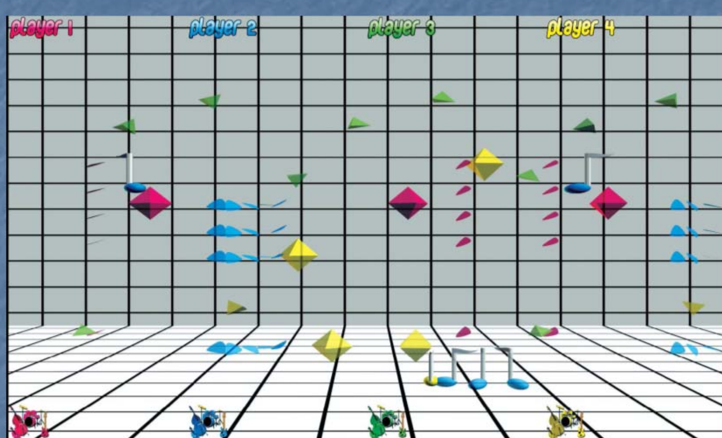
where, $\mathbf{x}^a = [\mathbf{x}^T\ \mathbf{v}^T\ \mathbf{n}^T]^T$, $\boldsymbol{\mathcal{X}}^a = [(\boldsymbol{\mathcal{X}}^x)^T\ (\boldsymbol{\mathcal{X}}^v)^T\ (\boldsymbol{\mathcal{X}}^n)^T]^T$, λ=composite scaling parameter, L=dimension of augmented state, $\mathbf{P_v}$=process noise cov., $\mathbf{P_v}$=measurement 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

One Man Band

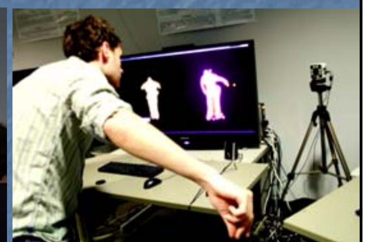


Bott et al., 2009

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

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)

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)

Next Class

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