3D User Interfaces for Games and Virtual Reality

Lecture #4: Video Game Motion Controllers

Spring 2013

Joseph J. LaViola Jr.

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

Razer Hydra

These Devices cost hundreds of Dollars!!

Lecture Outline

- Discuss video game motion controller hardware characteristics
  - Nintendo Wiimote
  - Microsoft Kinect
  - PlayStation Move
- Quick start guide for programming
- 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

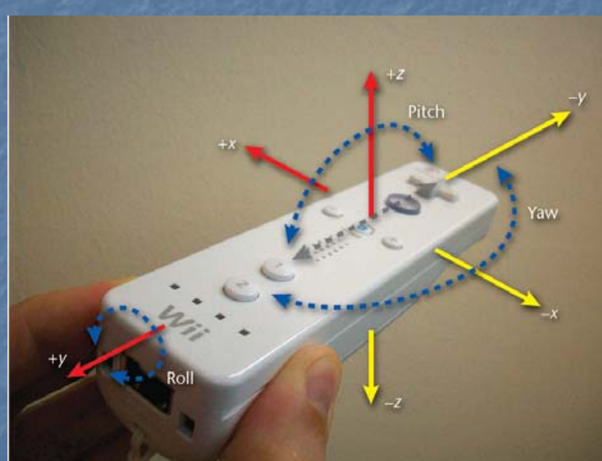
Boxing Gloves

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

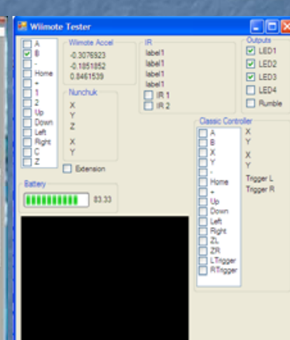
- Data from 3-axis accelerometer
  - senses instantaneous acceleration on device (i.e., force) along each axis
  - arbitrary units (+/- 3g)
  - always sensing gravity
    - at rest acceleration is g (upward)
    - freefall acceleration is 0
  - finding position and orientation
    - at rest – roll and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

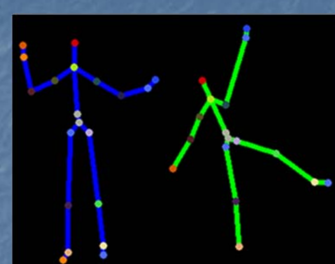
www.hardwaresphere.com

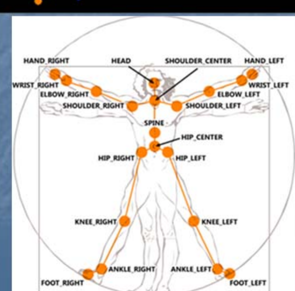
Kinect – Extracting 3D Depth

- 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)





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

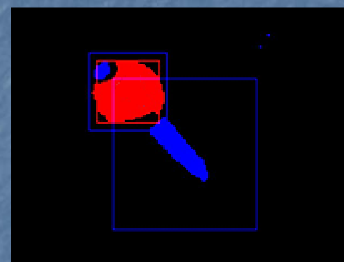
PlayStation Move – Hardware

- 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

www.hardwaresphere.com

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.

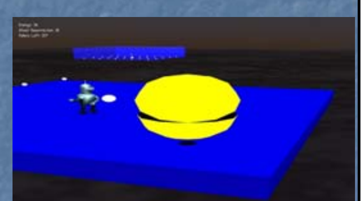
Algorithm 3.1: Unscented Kalman Filter (UKF) equations

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

Programming

Programming with the Wiimote

- Connect to computer
  - does not work for every bluetooth device
- Obtain Wiimote software
  - many variations and APIs (C,C++, C#, Java, Flash)
    - Brian Peek's API (www.coding4fun.com)
      - low level API
    - Paul Varcholik's XNA 3DUI Framework (www.bespokesoftware.org)
      - contained within larger framework
      - include gesture recognizer
    - Unity 3D
- Write code and enjoy (Wingrave et al. 2010)
  - integration
  - heuristics
  - gesture analysis and recognition



Spring 2013 CAP6121 – 3D User Interfaces for Games and Virtual Reality ©Joseph J. LaViola Jr.

Kinect Programming

- Two main approaches
  - NITE and Open NI
  - Microsoft Kinect SDK

OpenNI™

Kinect – Microsoft SDK

- Uses subset of technology from Xbox 360 dev version
- Access to microphone array
- Sound source localization (beamforming)
  - connection with Microsoft Speech SDK
- Kinect depth data
- Raw audio and video data
- Access to tilt motor
- Skeleton tracking for up to two people
- Examples and documentation

Kinect SDK – Joints

- Two users can be tracked at once
- <x,y,z> joints in meters
- Each joint has a state
  - tracked, not tracked, inferred
- Inferred – occluded, clipped, or no confidence
- Not tracked – rare but needed for robustness

Kinect SDK – Example

```
using Microsoft.Research.Kinect.Nui;
Runtime nui;

private void Window_Loaded(object sender, EventArgs e) {

     nui = new Runtime();

     try
     {
        nui.Initialize(RuntimeOptions.UseDepthAndPlayerIndex | RuntimeOptions.UseSkeletalTracking |
        RuntimeOptions.UseColor);
      }
      catch (InvalidOperationException)
      {
         System.Windows.MessageBox.Show("Runtime initialization failed. Please make sure Kinect device
         is plugged in.");
         return;
       }

       nui.SkeletonFrameReady += new EventHandler<SkeletonFrameReadyEventArgs>(nui_SkeletonFrameReady);
 }
```

Kinect SDK Example

```
void nui_SkeletonFrameReady(object sender, SkeletonFrameReadyEventArgs e)
        {
            SkeletonFrame skeletonFrame = e.SkeletonFrame;
            int iSkeleton = 0;
            Brush[] brushes = new Brush[6];
            brushes[0] = new SolidColorBrush(Color.FromRgb(255, 0, 0));
            brushes[1] = new SolidColorBrush(Color.FromRgb(0, 255, 0));
            brushes[2] = new SolidColorBrush(Color.FromRgb(64, 255, 255));
            brushes[3] = new SolidColorBrush(Color.FromRgb(255, 255, 64));
            brushes[4] = new SolidColorBrush(Color.FromRgb(255, 64, 255));
            brushes[5] = new SolidColorBrush(Color.FromRgb(128, 128, 255));

            skeleton.Children.Clear();
            foreach (SkeletonData data in skeletonFrame.Skeletons)
            {
                if (SkeletonTrackingState.Tracked == data.TrackingState)
                {
                    // Draw bones
                    Brush brush = brushes[iSkeleton % brushes.Length];
                    skeleton.Children.Add(getBodySegment(data.Joints, brush, JointID.HipCenter,
                                          JointID.Spine,JointID.ShoulderCenter, JointID.Head));
                    skeleton.Children.Add(getBodySegment(data.Joints, brush, JointID.ShoulderCenter,
                                          JointID.ShoulderLeft, JointID.ElbowLeft, JointID.WristLeft,
                                          JointID.HandLeft));
```


Kinect SDK Example

```
                skeleton.Children.Add(getBodySegment(data.Joints, brush, JointID.ShoulderCenter,
                                      JointID.ShoulderRight, JointID.ElbowRight, JointID.WristRight, JointID.HandRight));
                skeleton.Children.Add(getBodySegment(data.Joints, brush, JointID.HipCenter, JointID.HipLeft,
                                      JointID.KneeLeft, JointID.AnkleLeft,  JointID.FootLeft));
                skeleton.Children.Add(getBodySegment(data.Joints, brush, JointID.HipCenter, JointID.HipRight,
                                      JointID.KneeRight, JointID.AnkleRight, JointID.FootRight));

// Draw joints
   foreach (Joint joint in data.Joints)
   {
    Point jointPos = getDisplayPosition(joint);
    Line jointLine = new Line();
    jointLine.X1 = jointPos.X - 3;
    jointLine.X2 = jointLine.X1 + 6;
    jointLine.Y1 = jointLine.Y2 = jointPos.Y;
    jointLine.Stroke = jointColors[joint.ID];
    jointLine.StrokeThickness = 6;
    skeleton.Children.Add(jointLine);
   }
  }
  iSkeleton++;
 } // for each skeleton
}
```

Kinect SDK Example

```
Polyline getBodySegment(Microsoft.Research.Kinect.Nui.JointsCollection joints, Brush brush, params JointID[] ids)
        {
            PointCollection points = new PointCollection(ids.Length);
            for (int i = 0; i < ids.Length; ++i )
            {
                points.Add(getDisplayPosition(joints[ids[i]]));
            }

            Polyline polyline = new Polyline();
            polyline.Points = points;
            polyline.Stroke = brush;
            polyline.StrokeThickness = 5;
            return polyline;
        }
```

Microsoft Kinect SDK Documentation

http://msdn.microsoft.com/en-us/library/hh855347.aspx

PlayStation Move – Programming

- Move.Me
- Uses PS3 as device server
- Up to four controllers at once
- Controller state info
  - 3D position and orientation
  - 3D velocity and acceleration
  - 3D angular velocity and acceleration
  - button and tracking status
- Set color of sphere and initiate rumble feedback

Move.Me Code Snippets

Connecting to Move.Me Server

```
public void Connect(String server, int port)
        {
            _tcpClient = new TcpClient();
            _tcpClient.Connect(server, port);
            _udpClient = new UdpClient(0);
            Console.WriteLine("Initial recieve buffer size: {0}",
                              _udpClient.Client.ReceiveBufferSize);
            _udpClient.Client.ReceiveBufferSize = 655360; // 640 KB
            Console.WriteLine("Expanded recieve buffer size: {0}",
                               _udpClient.Client.ReceiveBufferSize);
            uint udpport = (uint)((IPEndPoint)_udpClient.Client.LocalEndPoint).Port;
            SendRequestPacket(ClientRequest.PSMoveClientRequestInit, udpport);
        }
```


Move.Me Code Snippets

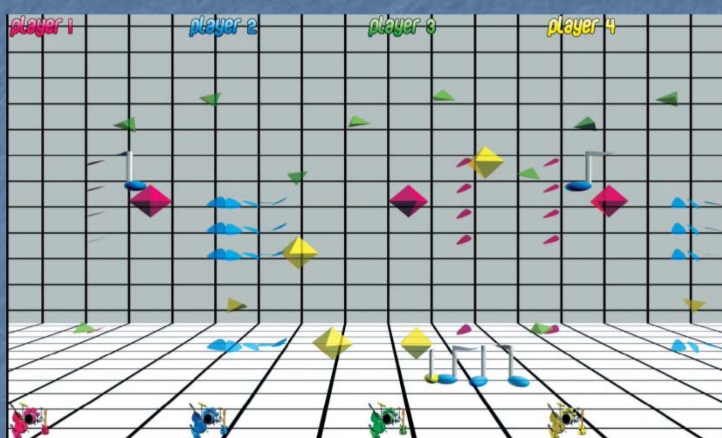
class PSMoveSharpGemState

```
public struct PSMoveSharpGemState
    {
        public Float4 pos;
        public Float4 vel;
        public Float4 accel;
        public Float4 quat;
        public Float4 angvel;
        public Float4 angaccel;
        public Float4 handle_pos;
        public Float4 handle_vel;
        public Float4 handle_accel;
        public PSMoveSharpPadData pad; // 4 bytes
        public Int64 timestamp;
        public float temperature;
        public float camera_pitch_angle;
        public UInt32 tracking_flags;
}
```

```
PSMoveSharpState state = moveClient.GetLatestState();
PSMoveSharpCameraFrameState camera_frame_state = moveClient.GetLatestCameraFrameState();
```

Case Studies

One Man Band

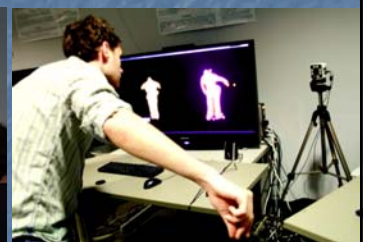


Bott et al., 2009

Real Dance

Charbonneau et al., 2009

Charbonneau et al., 2010



Charbonneau et al., 2011

Spring 2013 CAP6121 – 3D User Interfaces for Games and Virtual Reality ©Joseph J. LaViola Jr.

Football

Williamson et al., 2010

Kinect Football by Andrew Devine

Spring 2013 CAP6121 – 3D User Interfaces for Games and Virtual Reality ©Joseph J. LaViola Jr.

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

Conclusions – Which to Choose?

- Microsoft Kinect
- Positives
  - cost ~ $130
  - full body tracking
    - joint position
    - joint orientation (not yet)
  - 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
  - cost ~ $400 to $500
  - requires PS3 (positive as well)
  - does not track full body (more restrictive)

Next Class

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