3D User Interface Hardware

Lecture #8: Input Devices

Spring 2020

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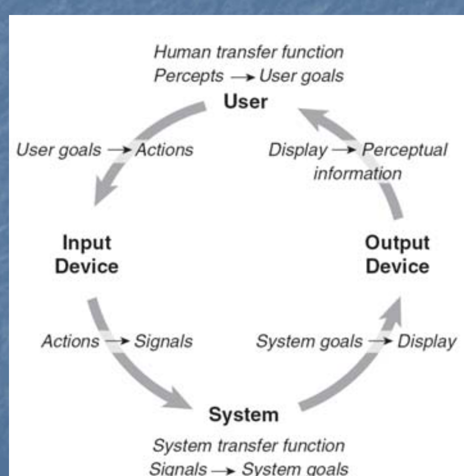
Interaction Workflow



Overview

- Input Device Characteristics
- Traditional Input devices
- Spatial Input devices
  - Active and passive sensing devices
  - Using sensors to track the user
- Complementary input for 3D UIs
- Special purpose input devices
- Strategies for building input devices
- Running case studies

Input Device Characteristics

- Degrees of freedom (DOF) – degree of freedom is a specific, independent way a body moves in space
  - 6 DOF has three position values (x, y, z) and three orientation values (yaw, pitch, roll)
- Input frequency
  - Discrete (one data value at a time)
  - Continuous (multiple data values in sequence)
  - Combination (discrete and continuous modes)

Input Device Characteristics

- Sensor type
  - Active sensors
    - Requires user to wear, hold, or manipulate the device to generate useful data
    - Can generate both discrete and continuous data
  - Passive sensors
    - Do not require user to hold or wear any input hardware to generate useful data
    - Placed in strategic location in the environment
  - Passive sensor could be used actively (user wearing a camera)

Input Device Characteristics

- Intended use
  - Locator
    - Determine position and/or orientation information
  - Valuators
    - Produce a real number value
  - Choice
    - Indicate a particular element of a set

Traditional Input Devices

- Typically used in desktop 3D UIs
  - Active sensing
  - Used in more immersive settings with appropriate mappings
- Types
  - Keyboards
  - 2D mice and trackballs
  - Pen- and touch-based tablets
  - Joysticks
  - Desktop 6-DOF input devices

Keyboards

- Classic example of active sensing input device
  - Contains a set of discrete components (buttons)
  - Often used in 3D modeling and computer games
- Traditional keyboards not conducive to immersive VR and mobile AR
  - Device not portable enough
- Several keyboard designs for alphanumeric characters in VR and AR

Keyboards

An example of a miniature keyboard (Used with permission from Microsoft)

A 12-key chord keyboard (Photograph courtesy of Doug Bowman)

Senseboard virtual keyboard prototype (Photograph courtesy of Senseboard Technologies AB)

2D Mice and Trackballs

- Another classic example of traditional desktop input device
  - 2D mice have variety of styles and designs
  - Trackball is essentially upside down mouse
    - Does not need flat surface to operate and can be held
- Two essential components
  - Continuous 2D locator
  - Set of discrete components
- Relative devices that report how far they move, rather than where they are in a fixed space

2D Mice and Trackballs

- Not designed to be portal for immersive VR, mobile, or AR applications
- Often used with keyboards in desktop computer games
- Trackballs can be designed for hand held use

Handheld wireless trackball device that could be used in AR, mobile, and immersive 3D environments

Pen- and Touch-Based Tablets

- Generate same type of input that mice do (2D pixel coordinates)
  - Stylus can move on or hover over the surface
  - One or more fingers for multi-touch
  - Most devices have buttons to generate discrete events
- Absolute devices – reports where the stylus or touch is in fixed reference frame of tablet surface

Pen- and Touch-Based Tablets

- Smaller device can be used in immersive VR, mobile, and AR settings
- Larger devices can be used in desktop and display wall settings
- Pen and paper style interface (pen and tablet metaphor)

A large pen- and touch-based LCD tablet allowing the user to draw directly on the screen. (Photograph courtesy of Wacom Technology)

Joysticks

- Traditionally used on desktop and video game settings
- Use active sensing and have a combination of continuous 2D locator and a set of discrete components
- Types
  - Isotonic: joystick handle must be returned to the neutral position to stop the cursor (rate control)
  - Isometric: have a large spring constant so they cannot be perceptibly moved (output varies with user force)

An isometric 3D input device. (Photograph courtesy of Andrew Forsberg, Brown University Graphics Group)

Desktop 6-DOF Input Devices

- Derivative of joystick
- Uses isometric forces to collect 3D position and orientation data
  - Push/pull for translation
  - Twist/tilt for orientation
- Designed specifically for 3D desktop

A desktop 6-DOF input device that captures 3D position and orientation data. (Photograph courtesy of 3Dconnexion)

3D Spatial Input Devices

- Important for UI to provide information about the user or a physical object's position, orientation, or motion in 3D space
  - Head position and orientation for motion parallax and correct stereoscopic rendering
  - Hand tracking to support 3D UI techniques
- Use both active and passive sensing technology

Sensing Technologies for 3D Tracking

- Critical for 3D UI to have accurate tracking
- Types
  - Magnetic sensing
  - Mechanical sensing
  - Acoustic sensing
  - Inertial sensing
  - Optical sensing
  - Radar sensing
  - Bioelectric sensing
  - Hybrid sensing

Magnetic Sensing

- Use transmitting device that emits a low-frequency magnetic field
- Small sensor, the receiver, determines its position and orientation relative to magnetic source
- Size of magnetic source determines tracking range

Magnetic sensor consists of an electronics unit, a magnetic field generator, and receivers that track the user or object. (Photograph courtesy of Polhemus Inc.)

Magnetic Sensing

- Have good accuracy (e.g., 0.01 inch in position and 0.01 degree in orientation)
  - Degrades as receiver moves away from the source
- Limited range
  - Not appropriate for outdoor and mobile AR
- Ferromagnetic or conductive (metal) objects will distort the magnetic field
  - Often need filtering or calibration algorithms to remove distortion

Mechanical Sensing

- Have rigid structure and a number of interconnected mechanical linkages combined with electromechanical transducers such as potentiometers or shaft encoders
  - As tracked object moves, linkages move as well to gather position and orientation data
- Very accurate with low latencies
- Bulky with limited range (not suited for mobile AR)
- Often a component of haptic devices

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Acoustic Sensing

- Use high-frequency sound emitted from source components and received by microphones
  - Use time-of-flight duration of ultrasonic pulses to determine position and orientation
- Types
  - Outside-in: source on the tracked object, with microphones placed in the environment
  - Inside-out: source placed in environment, microphones on the tracked object

Acoustic Sensing

- Inexpensive and lightweight
- Often have short range and low sample rates
- Accuracy suffers if acoustically reflective surfaces are present

Acoustic sensing device (Photograph courtesy of Logitech International)

Inertial Sensing

- Use a variety of inertial measurement devices
  - Angular rate gyroscopes
  - Linear accelerometers
  - Magnetometers
- Often combined into single package called inertial measurement unit (IMU)

Inertial Sensing

- Tracking system is in the sensor so range is unlimited
- Produce data at high sampling rates
- Suffer from error accumulation from bias, noise, and drift
- Most inertial sensors only track orientation for 3D UIs
- Often need sensor fusion algorithms such as Kalman filters to improve accuracy

Optical Sensing

- Use measurements of reflected or emitted light
- combine computer vision with optical sensors
- Many different types
  - Single webcams
  - Multiple cameras
  - Depth cameras
  - 360 degree cameras
- Inside-out or outside-in
- Markers or markerless

Optical Sensing

- Depth cameras extract 3D representations of a user or environment
- Time of flight
  - Determine the depth map of a scene by illuminating it with a beam of pulsed light and calculating the time it takes for the light to be detected on an imaging device after it is reflected off of the scene
- Structured light
  - Use a known pattern of light (often infrared) that is projected into the scene; an image sensor captures this deformed light pattern based on the shapes in the scene and extracts 3D geometric shapes using the distortion of the projected optical pattern
- Stereo camera pair
  - Two cameras capture synchronized images of the scene, and the depth for image pixels is extracted from the binocular disparity

Optical Sensing

- Marker-based outside-in systems
  - Sensors mounted at fixed locations in the environment
  - Tracked objects are marked with active (e.g. retro-reflective markers) or passive landmarks (e.g., colored gloves)

Optical Sensing

Marker-based outside-in optical tracking system Multiple camera sensors are placed strategically in the environment, and the user wears several retroreflective markers. (Photograph courtesy of Vicon Motion Systems Ltd.)

Marker-based outside-in optical hand tracking system where a single camera sensor is used and the markers are colored gloves with unique patterns (Photograph courtesy of Robert Wang)

Optical Sensing

- Marker-based inside-out systems
  - Place optical sensors on the user or tracked object while the landmarks are placed in the environment
- Many different types of landmarks
  - Active LED beacons
  - Passive fiducials (cards with recognizable patterns)

Optical Sensing

Marker-based inside-out tracking system with active LED beacons mounted on the ceiling and the camera sensors located in a handheld object. (Photograph of the HiBall-3000 Tracker courtesy of 3rd Tech, Inc.)

Marker-based inside-out tracking system that uses several fiducial markers with known unique patterns placed strategically on the walls and ceiling of a room.
(Photograph courtesy of Valve)

Optical Sensing

- Markerless inside-out systems
  - Place optical sensors on the user or tracked object and make use of the physical environment itself as markers
- Two main approaches
  - Feature-based approach
  - Model-based approach

Optical Sensing

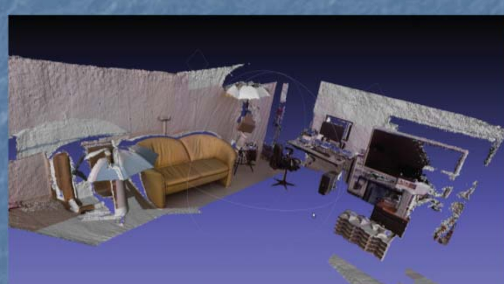
- Markerless feature-based approach
  - Finds the correspondence between 2D image features and their 3D world coordinate equivalents
  - Example algorithms include SIFT, SURF, FREAK

Tracking using the PTAM algorithm. Real-world feature points are used in conjunction with the SLAM concept. (Photograph courtesy Georg Klein and David Murray, University of Oxford)

Optical Sensing

- Markerless model-based approach extracts pose information based on tracking known or acquired models of real-world objects
  - Early approaches used CAD models
  - SLAM (Simultaneous Localization and Mapping)
    - Create and update a map of the physical environment while simultaneously determining pose within it

Optical Sensing



A 3D model of an indoor physical environment using a depth sensor and RGB sensor. This model can then be used during SLAM or for user tracking once the model is created. (Image courtesy of Raphael Favier and Francisco Heredia, VCA Lab, Eindhoven University of Technology)

Optical Sensing

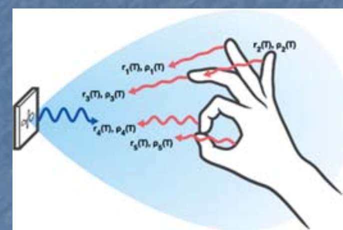
- Setup can be challenging and complex
  - Many parameters must be set
    - Number of cameras
    - Placement of the cameras
    - Visual background
    - Design and placement of landmarks if any
    - What parts of the body and how many people need to be tracked
  - Must deal with occlusion
  - Not as accurate as other tracking solutions (mechanical, electromagnetic)
- Have a clear advantage in that the user can be completely untethered from the computer
- Ideal solution if problems are adequately addressed

Radar Sensing

- Uses modulated electromagnetic waves sent toward moving or static targets that scatters transmitted radiation, with some portion of the energy redirected back toward the radar where it is intercepted by a receiving antenna
  - Time delay, phase or frequency shift, and amplitude attenuation capture rich information about the target's properties

Millimeter Wave Radar Sensing

- Originally not for tracking small objects
- Can use millimeter wave radar
  - Illuminate the user's hand with a 150-degree-wide radar beam
- Can track hand and finger movement with high accuracy



Millimeter wave radar sends a wide radar beam at high frequencies to gather dynamic scattering centers of a user's hand that can be then used for 3D hand gesture recognition. (Image courtesy of Ivan Poupyrev, Google)

Millimeter Wave Radar Sensing

- Main advantage – subtle hand movements can be detected
  - Lead to wide variety of different interface controls for selection and manipulation, navigation, and system control
- Main disadvantage – does not actually capture the skeletal structure of a hand
  - Does not actually track the hand's position and orientation in space
  - Requires machine learning techniques to do 3D gesture recognition

Bioelectric Sensing

- Measure electrical activity in the body
- Main bioelectric sensor technology used in 3D UI is electromyography (EMG)
  - Detects electrical potential generated by muscles when electrically or neurologically activated
- Data is noisy, requires advanced signal processing or machine learning
  - More useful for 3D gestural input

An example of EMG sensors applied to a user's forearm. (Photograph courtesy of Desney Tan, Microsoft Research)

Hybrid Sensing

- Put more than one sensing technology together
  - Increase accuracy
  - Reduce latency
  - Provide a better overall 3D interaction experience
- Examples
  - Inertial and ultrasonic sensing
  - Vision and inertial sensing
- Combining sensor technologies makes algorithms more complex
  - Sensor fusion algorithms (e.g., Kalman, Extended, Unscented filters) often needed

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Tracking the Body for 3D UI

- 3D UIs often require information about a user's position, orientation, or motion in 3D space to support 3D spatial interaction techniques
  - Head
  - Hands
  - Fingers
  - Eyes
  - Body

Tracking the Head, Hands, and Limbs

- Head and hand tracking cornerstone of 3D UI
- Can be done with both active and passive sensing
- Active sensors (e.g., electromagnetic, inertial)
  - Small device is placed on the area or areas that need tracking
  - Sensors can be placed on user's 3D glasses
  - Sensors can be placed on back of user's hand
    - Make it easier to perform different gestures and actions
- Passive sensors (e.g., optical sensing)
  - Can be an unobtrusive approach to head, hand, and limb tracking
  - Challenging to use for mobile AR

Tracking the Fingers

- Can be useful to have detailed tracking information about the user's fingers
  - How the fingers are bending
  - Whether two fingers have made contact with each other
- Active and passive sensing both work well

Tracking the Fingers

- Data gloves (active sensing)
  - Typically use bend-sensing technology to track the fingers, postures and gestures
  - Data given as joint angle measurements
  - Many different designs
  - 5 to 22 DOF
- Technologies
  - Flexible tubes with a light source at one end and a photocell at the other
  - Fiber-optic sensors
  - Resistive ink sensors
  - Strain-gauge bend sensors
  - Inertial measurement units (IMUs)

Tracking the Fingers

A bend-sensing data glove that can track the fingers. (CyberGlove Model III photograph
courtesy of CyberGlove Systems)

A data glove that uses accelerometers, gyroscopes, and magnetometers to capture
information about each finger. (NuGlove Photograph courtesy of AnthroTronix)

Tracking the Fingers

- Data gloves
  - Useful for hand posture and gesture recognition
  - 3D virtual representation of virtual hand
  - Major advantage is large number of DOF
  - Disadvantage is user must wear a device
  - Sometimes need calibration on a user-by-user basis

Tracking the Fingers

- Passive sensing provide unobtrusive finger tracking
  - Depth cameras can extract finger position
  - Millimeter wave radar can track moving fingers
- Light of sight issues can cause problems
- Do not offer measurement range of data glove

Example of tracking the fingers using a depth camera, making use of passive sensing (Photograph courtesy of Arun Kulshreshth)

Tracking the Eyes

- Eye trackers used to determine where the user is looking
  - Based primarily on optical sensing
  - Device tracks the user's pupils using corneal reflections detected by a camera
- Device can be worn (active) or placed in environment (passive)
- Used both as evaluation device and for interaction techniques (i.e., gazed directed navigation and object selection)

Tracking the Eyes

Example of user-worn eye-tracking device that performs pupil tracking to determine eye gaze (Photograph courtesy of SensoMotoric Instruments, GmbH(SMI), www.smivision.com)

Passive eye-tracking device that does not require the user to wear anything (Photograph courtesy of Joseph J. LaViola Jr.)

3D Mice

- Handheld or user-worn input devices that combine position, orientation, and/or motion tracking with physical device components (buttons, sliders, etc.)
- Users physically move 3D mice in 3D space instead of just moving the device along a flat surface
- Primary means of communicating user intention in 3D UIs for a variety of VR, AR, and mobile applications

Handheld 3D Mice

- Place a motion tracker inside a structure that is fitted with different physical interface widgets
  - Many different designs for the device housing
- Modern devices are wireless
  - Commonly used as motion-based game controllers

The Wanda input device containing a 6 DOF tracker, three buttons and an isomorphic ball. (Photograph courtesy of Ascension Technology Corporation)

Handheld 3D Mice

Examples of modern 3D mice that make use of optical and inertial sensing to produce 3D position, orientation, and motion data. Since users hold a 3D mouse, their hands are effectively tracked in 3D space, and coupled with buttons, analog controllers, dials, etc., these 3D mice provide for a variety of mappings from device to 3D interaction technique. (Photograph courtesy of Joseph J. LaViola Jr.)

User Worn 3D Mice

- Have user wear device instead of hold them
  - Extension of user's hand when worn on finger
  - Needs to be lightweight

A user pressing one of the multilevel buttons on the FingerSleeve. (Photograph reprinted from Zeleznik et al. (2002), © 2002 IEEE Press)

Example of a finger-worn 3D mouse that supports gesture-based interaction (Photograph courtesy of Nod, Copyright © 2016 Nod Inc www.nod.com)

Complementary Input for 3D User Interfaces

- Not all input mechanisms for 3D UI are spatial
- Examples
  - Speech input
  - Brain input

Speech Input

- Powerful approach to interacting with 3D applications
- Capture speech signals with acoustic sensing devices such as a single microphone or array of microphones
- Signals are taken and run through speech or spoken dialogue recognizers to interpret the content of the speech
- Provides complement to other input devices (multimodal interaction)

Brain Input

- Use neuronal activity of brain to control devices and issue commands in both physical and virtual worlds
- Input device monitors brainwave activity primarily through electroencephalogram (EEG) signals
  - EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain
  - User wears noninvasive headband or cap
  - Invasive approaches also possible but not practical
- Requires signal processing/machine learning software to make use of signals

Brain Input

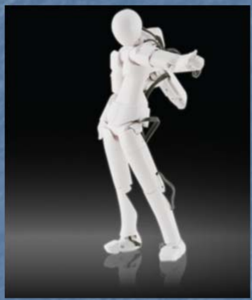
- Could be used to translate and rotate 3D objects or move a robotic arm
  - Devices still rudimentary and can be challenging to use

Head-worn 14 channel brain–computer input device that reads EEG information from strategically placed points on the scalp (Photograph courtesy of Emotiv)

Special-Purpose Input Devices

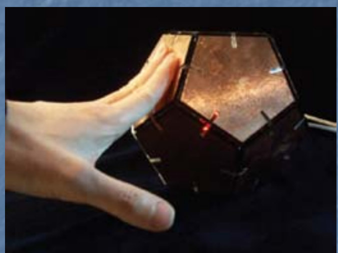
- Devices are often designed for specific 3D applications
  - Specific output hardware
  - Targeted user populations

Special-Purpose Input Devices



A 3D input device used for posing 3D characters. The device uses 32 sensors across 16 body joints so users can manipulate the mannequin to create particular poses that are translated to virtual characters. (Photograph courtesy of Clip Studio)

Special-Purpose Input Devices



The iSphere, a 24-DOF device for 3D modeling of parametric surfaces. This 12-sided capacitive 3D input device was designed and tested with Maya in Ted Selker's Context aware computing group at MIT Media lab. The goal was to create and explore a more intuitive physical 3D input and manipulation approach. (Photograph courtesy of Jackie Lee and Ted Selker)

Special-Purpose Input Devices

The CavePainting Table used in the CavePainting application. It uses a prop-based design that relies upon multiple cups of paint and a single tracked paintbrush. The paintbrush is dipped into the cups to get different paint styles. (Photograph reprinted from Keefe et al. 2001, © 2001 ACM; reprinted with permission)

Special-Purpose Input Devices

Transparent palettes used for both 2D and 3D interaction. (Williams et al. 1999; photographs courtesy of Fakespace Labs, Mountain View, California)

Special-Purpose Input Devices

The CAT is designed for surround-screen display environments. It combines 6-DOF input with 2D tablet interaction. (Photograph courtesy of the Iparla Team [LaBRI–INRIA])

Special-Purpose Input Devices

A 3D input device used specifically for children with cerebral palsy. It can be connected to games to better engage these children when they perform various exercises. (Photograph courtesy of Hariraghav Ramasamy)

Do It Yourself (DIY) Input Devices

- Not limited to commercially available input devices
- Develop novel and useful devices for 3D UIs using simple electronic components, sensors, and household items
- Maker revolution makes it easier than ever

Strategies for Building Input Devices

- Need to consider device's intended functionality
  - Help determine what types of physical device components will be required
  - Choose appropriate sensors for given device
    - Pressure sensors
    - Bend sensors
    - Potentiometers
    - Thermistors (for sensing temperature)
    - Photocells (for sensing light)
    - Simple switches
    - IMUs

Strategies for Building Input Devices

A variety of different sensors that can be used to for DIY input devices. The image shows light, sound, distance, magnetic, accelerometer, vibration, touch, and gas sensors. (Photograph courtesy of RobotShop, Inc.)

Strategies for Building Input Devices

- Need to house sensors into device
  - The user must be able to interact with them comfortably (i.e., support proper ergonomics such as grip)
  - Sensor placement can also be affected by the geometry of the device itself

Strategies for Building Input Devices

- Need to build physical housing for 3D input device
  - Can use Lego bricks or modeling clay to try different designs and prototypes
- Main approach is the 3D printer
  - Use modeling software to design housing

Connecting the DIY Input Device to the Computer

- Require some type of logic the user needs to specify for the computer to understand the device data
- Main approach is the microcontroller
  - Small computer that can interface with other electronic components through its pins
  - Two most common are Arduino and Raspberry Pi
  - Communication through USB port or wirelessly though Bluetooth, Wi-Fi, RF

Connecting the DIY Input Device to the Computer

- Main approach
  - Builds the electronics on a prototyping board
  - Write microcontroller code (Basic, C, many other packages)
  - Test and debug
  - Attach microcontroller and electronics to an appropriate circuit board
  - Connect to application software

Case Studies

VR Gaming Case Study

- Full 6 DOF head tracking
- 6 DOF tracking of both hands
- Many different possibilities but 3D mice seem post appropriate
  - Can also be incorporated into game design by using the physical controller as a handle for a virtual tool

Case Studies

VR Gaming Case Study

- Key concepts:
  - Completely natural interaction is not always possible or desirable, and this should be considered when choosing input devices
  - Handheld 3D mice provide a familiar bridge between traditional desktop/console interaction and VR
  - Buttons are more reliable than vision-based gesture tracking—gestures are not recognize every time
  - Gesture-based interaction can be incorporated into systems using many different types of input, not just bare-hand tracking

Case Studies

Mobile AR Case Study

- Requires accurate tracking of the handheld device in outdoor settings
  - Used special tracking installation (an Ubisense ultra-wideband tracking system) mounted on a 4 x 4 vehicle that could be taken into the field
  - Also make use the embedded GPS and inertial sensors

Case Studies

Mobile AR Case Study

- Many design interactions for user input
  - Support gripping device with one hand
  - Ultimately use pen to interact with touch screen on device

Pen input while using the handheld setup. (Image courtesy of Ernst Kruijff)

Case Studies

Mobile AR Case Study

- Key concepts:
  - For mobile AR, provide easily accessible controllers that perform well if direct touchscreen–based control is not possible
  - Integrate all devices without destroying ergonomics
  - Consider how controllers are operated while holding the device in a certain grip

Conclusion

- Presented a variety of different input and device types that can be and have been used in 3D UIs
- Discussed input device characteristics
- Looked briefly at traditional input devices
- Focused on 3D spatial input devices that capture a user or object's position, orientation, or motion in space
- Looked at complementary input technologies and special-purpose input devices
- Examined strategies for DIY input device design and development
- Ready to move on to 3D interaction techniques

Next Class

- Selection and Manipulation
- Readings
  - 3DUI Book – Chapter 6