Part 8:
Interaction in VR: Manipulation

Virtuelle Realität
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Overview

- Control Methods
- Selection Techniques
- Manipulation Techniques
- Taxonomy

Further reading:


Why Manipulation?

- Major method of interaction with physical environments
  - touching, picking, manipulating objects using the hands is a main way for humans to affect their surroundings

- Major method of interaction with virtual environments
  - alternatives: voice, gaze, gesture

- Affects the quality of entire 3D interface
  - if user cannot efficiently manipulate objects in the virtual environment, then other high-level tasks cannot be accomplished

- Design of 3D manipulation techniques is difficult

Manipulation Techniques:
Design Objectives

- Design 3D manipulation techniques
  - that conform to used input and output devices
  - that are effective in desired task conditions
    - object distance: within/outside the reach
    - object sizes and shape: small, large, flat objects
    - object density
    - accuracy
  - that allow high user performance and comfort
    - independent of user characteristics such as right- or left handedness, level of expertise, age, ...
  - that are easy to learn
  - that conform to external constraints
    - e.g. can user move or not (i.e. how much physical space is available)?
    - e.g. price
    - --
Control Methods for Manipulation Tasks

- Direct User Control
- Indirect Control
  - Physical Control
  - Virtual Control
  - Agent Control

Direct User Control

- Participant interacts with virtual objects as they would real objects (e.g. grabbing)
- Generally use gesture recognition to interpret user’s actions
  - needs VR gloves
Physical Control

- Real buttons, switches, etc.
- By putting the interface in the real world, the user can receive some haptic feedback.
- Controls mounted on prop can act independently (e.g. menus) or in concert (e.g. point + click) with the prop’s position.

Virtual Controls

- Controls that are manifested entirely in the virtual world:
  - ... although physical controls may be used to manipulate the virtual controls.
  - E.g. virtual representations of buttons, sliders, steering wheels, ...
  - Allows a limited number of physical controls to be used to interact with a large number of virtual controls.
    - like a mouse can control sliders, dials, etc. in 2D GUIs
  - May lose haptic feedback.
Agent Control

- Tell another entity to do your bidding
- Using voice recognition
  - and possibly gesture recognition
  - "move <pointing> that table over <pointing> there"

Manipulation Tasks

- Specific, complex manipulation tasks
  - e.g. sculpting, operating a specific virtual machine, ...

- Canonical 3D manipulation tasks
  - select object
  - position, rotate, scale object
  - (change object or environment attributes)

- Variables in manipulation tasks
  - distance to object
  - object size
  - required object translation (amount, depth manipulation)
  - amount of rotation
  - ...

Selection and Manipulation

- **Selection**
  - selecting direction
  - selecting items
  - selecting values

Direction selection

- **Direction selection**
  - useful for travel control (navigation)
  - useful for item selection (select object in a direction)
  - useful for object manipulation (e.g. specify a desired object position)

- **Methods**
  - pointer-directed
  - gaze-directed
  - crosshair-directed
  - torso-directed
  - device-directed
  - coordinate-directed
  - landmark-directed selection
Direction selection

- **Pointer-directed selection**
  - Familiar to most users from real world communication
  - Requires tracking the hand

- **Gaze-directed selection**
  - What I’m looking at is what I’m interested in
  - Also familiar from real world interaction
  - Requires only that the head be tracked
  - Forces the user to look in the direction they are selecting

- **Crosshair-directed**
  - Vaguely familiar to many people
  - Requires tracking both the head and the hand
  - Requires use of both the head and the hand

- **Torso-directed**
  - Good for indicating direction of travel (very common for self-locomotion in real world)
  - Requires tracking of the torso

- **Landmark-directed selection**
  - Direction can be specified relative to some object in the environment
  - e.g. "toward the water tower"
  - Requires some means of indicating the landmark object (e.g. voice).
**Direction selection**

- Device-directed
  - Uses a physical control
  - E.G. joystick, flystick, steering wheel
  - May be relative to an absolute reference (e.g. north) or to current direction

- Coordinate-directed
  - May be relative to an absolute reference (e.g. "30 degrees east of north"), or to current direction (e.g. "turn left 45 degrees").
  - Coordinates must be input by a value-selection technique (e.g. voice).

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**Item Selection**

- contact-select
- 3D-cursor-select
- point-to-select
- aperture-select
- image-plane techniques
- select-in-mini-world
- name-to-select
- menu-select

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Virtual hand technique
(from Poupyrev et al., 1996)

Virtual pointer technique
(from Bowman et al., 1997)
**Item Selection**

- **Selection by contact** ("Virtual Hand")
  - Part of the avatar of the user (or prop held by the user) must come in contact with the desired object.
  - May require a trigger event to select, or may require a trigger event to manipulate, or the contact itself may trigger an event.
  - Feedback is good. May be provided visually, aurally, haptically

  + Most natural selection technique
  - Limited area of manipulation

- **Go-Go (Extension of simple contact-selection with "Virtual Hand")**
  - Extends the virtual hand’s reaching distance
  - If the user’s hand is close to body, the mapping between the physical and virtual hands’ position is 1-to-1
  - If the hand is extended beyond a threshold, the mapping becomes non-linear

  + Seamless 6DOF manipulation in a large range of distances
  - Manipulation range is still limited
  - Overshoot with large distances

[Mapping function for the Go-Go (Poupyrev, et al. 1996)]
Item Selection

- **Selection by 3D cursor**
  - The user controls a 3D cursor by some means (e.g., flown by joystick)
  - Selection is generated when the cursor comes in contact with an object
  - If cursor is attached to a hand held prop, then this is very similar to selection-by-contact

- **Selection by pointing**
  (Ray-Casting, Virtual Pointer)
  - Use direction of pointing to indicate an object
  - Similar to contact-selection, but object can be out of reach
  - Familiar to most users from real world experience
  - User only needs to control 2 DOFs
  - Empirically proven to perform well

- **Shape of beam**
  - ray (finite, infinite)
  - cone ("flashlight", "aperture")
  - may be visualized or not
Item Selection

- **Selection by aperture**
  - Improvement of simple ray-casting (can control diameter of selection cone)
  - "Aperture" is usually indicated with fingers of the user
  - Requires tracking of "aperture" (e.g. fingers).
  - Requires tracking of the eye location (i.e. head)
  - Requires knowing which eye the user is using
  - Similar to direction selection using crosshairs

  + interactive and intuitive object disambiguation
  - inefficient positioning / rotation

Aperture technique (Forsberg, et al. 1996)

- **Image-Plane Techniques**
  - User selects an object by touching its position on an image plane (e.g. table-top of the responsive workbench, a wall of a cave, …)
  - Select object underneath the user’s finger (occlusion, "sticky finger") or select object between thumb and index finger
  - Manipulation:
    - manipulate 2D projection
    - or, scale object down & bring within user’s reach ("Scaled-World-Grab"; Mine, 1997)

  + Easy, intuitive selection
  - remote object manipulation difficult
**Item Selection**

- **Selection by menu**
  - Familiar to most computer users
  - Requires a list of all possible items
  - Items don’t have to be objects in the world
  - Requires some means of input to indicate that a menu choice is selected

- **Selection in Miniature World (World-in-Miniature, WIM)**
  - A subset of the real world is represented as a small model on a palette
  - Exocentric frame of reference
    - i.e. not egocentric as virtual hand, virtual pointer
  - Allows 6DOF manipulation at any distance
  - Difficult to precisely manipulate small objects

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**Menu positioning**

- **fix**
- **head-centered**
- **body-centered**
- **hand-centered**

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**Item Selection**

- **Selection by naming**
  - Very familiar to users
  - Requires voice recognition

  - Requires that the user know the name of the object
  - Possibly, more generic descriptions
    - "the yellow object in the back"

  - Might be ambiguous
**Evaluation of Item Selection Techniques: Ray-casting v. Image-plane v. Go-Go**

- Two experimental evaluations
  - Poupyrev et al., 1998, and Bowman et al., 1999

- Ray-casting and image-plane are generally more effective than Go-Go
  - Exception: high precision selection, e.g. small or far away objects (about 4 degrees of field of view), can be easier with Go-Go. cf. Fitt’s law

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**Alphanumeric Value Selection**

- Avoided in most virtual reality interactions … but sometimes necessary
- Typically uses some form of physical or virtual control (e.g. dials, keyboard, tablet)
- May use a menu of pre-selected values
- May use voice input

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(S. Conrad, 2007)
Guidelines for Designing Selection Techniques
Bowman, 2002

- Use the natural virtual hand technique if all selection is within arms reach
- Use ray-casting techniques if speed of remote selection is a requirement
- Ensure that the chosen selection technique integrates well with the manipulation technique to be used
- Consider multimodal input for combined selection and command tasks
- If possible, design the environment to maximize the perceived size of objects

Manipulation

Once we’ve selected an object, we may want to manipulate it

A variety of operations we may wish to perform:
- object positioning and scaling
- exerting force on a virtual object
- object attribute modification
- altering state of virtual controls
- global attribute modification
- travel controls
  - (see next lecture on Navigation in VEs)
Manipulation

- **Object positioning and scaling**
  - Changing the shape and position of an object without regard to physics
  - Can use any of the control methods (direct, physical, virtual, agent), but the direct method is the most common
  - Scale and rotation operations also require specification of some origin or axis to operate about
  - Constrained positioning: Snap-to-grid, lock-to-surface, snap-to-object, ...

- **Exerting force on a virtual object**
  - Using a world model with physics
  - Pushing, pulling, supporting, hitting objects, etc.
  - Generally used for worlds that attempt to be more "realistic."
  - Moving objects is done by pushing them, or picking them up and setting them down.

... involves much more than just interaction

Example: Constrained Manipulation in Virtual Design / Assembly Simulation
Manipulation

- **Object attribute modification**
  - Changing the parameters that control how an object is rendered or behaves, add constraints, ...
  - These operations typically do not mimic the real world (e.g. setting the color of a fence vs. painting it)

- **Altering the state of virtual controls**
  - Depending on how the virtual control is designed, this can be viewed as a subset of "Object positioning" or of "Object attribute modification."
  - The changed value of the virtual control may then be used to select, modify or steer some other object in the world.

- **Global attribute modification**
  - Similar to specific object attribute modification, but without requiring the object to be selected.
    - e.g. adjusting the overall volume of the world
    - e.g. adjusting the time of day and therefore the ambient light in the world

Common manipulation techniques

- Simple virtual hand
- HOMER
- Scaled-world grab
- World-in-miniature
**Simple virtual hand technique**

- Attach object to virtual hand, by making object a child of the hand
- On release, reattach object to world
- Also applies to Go-Go (and other arm-extension techniques) and ray-casting

**HOMER technique**

Bowman, D., & Hodges, L. (1997)

Hand-Centered
Object
Manipulation
Extending
Ray-Casting

Hybrid method:
- Select: ray-casting
- Manipulate: hand
Scaled-world grab technique


- Often used with occlusion (image-plane item selection)
- At selection, scale user up (or world down) so that virtual hand is actually touching selected object
- User doesn’t notice a change in the image until he moves
- At release:
  - Re-attach object to world
  - Scale user down to original size
  - Ensure that eye remains in same position

Discussion of hybrid manipulation techniques

HOMER (Bowman et al., 1997)
World-scale grab (Mine et al., 1997)

- Advantages:
  - Easy selection: ray-casting or image plane
  - 6DOF Manipulation on a wide range of distances
  - Virtual manipulation within normal area of reach

- Disadvantages
  - Moving objects from within reach to far is problematic
  - Inconsistency in mappings between physical and virtual hands movements
World-in-miniature (WIM) technique
http://www.cs.cmu.edu/~stage3/publications/95/conferences/chi/paper.html

- "Dollhouse" world held in user’s hand
- Miniature objects can be manipulated directly
- Moving miniature objects affects full-scale objects
- Can also be used for navigation

On selection:
- Determine which full-scale object corresponds to the selected miniature object
- Attach miniature object to v. hand (w/out moving object)

Each frame:
- Copy local position matrix of miniature object to corresponding full-scale object

Guidelines for Designing Manipulation Techniques
Bowman, 2002

- Reduce the number of degrees of freedom to be manipulated if the application allows it. Provide general or application-specific constraints or manipulation aids.
- Allow direct manipulation with the virtual hand instead of using a tool (e.g. virtual light ray)
- Avoid repeated, frequent scaling of the user or the environment
- Use indirect depth manipulation for increased efficiency and accuracy
Taxonomy of Selection and Manipulation Techniques (1/3):
Selection Techniques
Bowman & Hodges, 1999

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Taxonomy of Selection and Manipulation Techniques (2/3):
Manipulation Techniques
Bowman & Hodges, 1999

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Taxonomy of Selection and Manipulation Techniques (3/3): Release Techniques
Bowman & Hodges, 1999

- **Release**
  - **Indication to drop**
    - gesture
    - button
    - voice command
  - **Object final location**
    - remain in current location
    - adjust position
    - adjust orientation

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Two-Handed Interfaces

- Many natural manipulation tasks are two-handed
- Use of bimanual interfaces not common in VR applications
  - extra costs for second VR glove
  - conventional desktop interfaces commonly use only a single input device (mouse)
- Many bimanual tasks are asymmetric (Guiard, 1987)
  - non-dominant hand defines a frame of reference, defines a spatial context
  - dominant hand performs fine manipulations
- Bimanual interfaces allow the simultaneous specification of multiple parameters
  - e.g. grasping an object with two hands implies an rotation axis
  - in single handed interfaces, such actions often require several steps; e.g. specify rotation axis, specify rotation amount

Voodoo Dolls technique for manipulation at a distance (Pierce et al. 1999)

Tangible Interaction with Props (Hinkley et al. 1994)
**Grasp Taxonomy** by Cutkosky & Wright

**Grasp Analysis** – Low and Mid Level Grasp Features  
Weber, Heumer & Jung, 2005

- Track finger and hand joint angle values with CyberGlove
- Modified by virtual collision sensors and joint constraints to „realistic“ grasp posture
- Contact Points of Hand with Object (see Contact Web of Kang/Ikeuchi)
Grasp Analysis - High Level Grasp Features
Weber, Heumer & Jung, 2005

- Based on low-level and medium-level features, grasp can be classified w.r.t. taxonomy
- Grasp Category yields further features:
  - prehensile / non-prehensile, volar / non-volar, power / precision grasp
- Further reasoning can be performed based on object type and grasp features
  - For instance grasp purpose: displacement or use etc.
  - Basis for AI methods (object specific reasoning, …)

Grasp Taxonomy by Schlesinger, 1919

- G. Schlesinger „Der Mechanische Aufbau der künstlichen Glieder“, 1919
- 6 grasp types: Cylindrical, Tip, Hook, Palmar, Spherical und Lateral
- few, but elementary classes
Grasp Analysis – A Machine Learning Approach

- Direct classification of raw data glove sensor readings w.r.t. Schlesinger taxonomy
- No calibration of data glove!
- Evaluation of > 30 classifiers of data mining WEKA, data mining software, Waikato University, New Zealand

6 classifier categories
- Bayes: probabilistic reasoning
- Function approximators: learning of functions, e.g. neural nets
- Lazy Learners
- Decision Trees
- Rules: induction of logical rules
- Meta: combination of simple classifiers to hierarchies or cascades

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Table 4: Results of the classifier evaluation with best classifier in bold and not significantly different

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**Myths and Reality**
Poupyrev, SIGGRAPH 2000

- **Myth**: Manipulation techniques should strictly imitate real-world manipulation.
  - **Reality**: Most manipulation techniques depart from real world manipulation to a greater or lesser degree.

- **Myth**: We should develop universal manipulation techniques.
  - **Reality**: There is no one best technique for every condition of immersive manipulation.

- **Myth**: Manipulation techniques should be 6DOF.
  - **Reality**: Constraining DOF of manipulation can be an efficient method of making interaction easier.

- **Myth**: To improve interaction, we should design better devices and interaction techniques.
  - **Reality**: We can design VE so that existing techniques allow for maximum performance.