Contributions to the Design of Novel Hand-based Interaction Techniques for Virtual Environments

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Using our hands in virtual environments

- **The hand in the real world**
  - Action
    - Strength or precision
    - High flexibility
  - Perception
    - Different scales
    - High sensitivity to touch

- **The hand in virtual environments**
Applications of hand-based interaction

Virtual prototyping

[Dai, 1996]  
[Seth, 2006]

Virtual training

[Cornaglia, 2004]  
[Dinsmore, 1997]

Dextrous interaction

[Cutler, 1997]  
[Veit, 2008]
Context of hand-based interaction in VR

Virtual reality (VR)

Immersive computer simulations that users can interact with and perceive

3D interaction techniques

Methods allowing users to accomplish a task via the user interface

Haptic feedback

Sensory information relating to the sense of touch
Challenges of hand-based interaction

**Challenge 1**
Handling the many DoF of the hand

**Challenge 2**
Providing convincing haptic sensations

Degrees of freedom (DoF)
Independent parameters of a system defining its mechanical configuration
Related work – The human hand

- **Mechanics of the hand**
  - Highly articulated skeleton
  - Extrinsic muscles
  - 27 DoF in a small volume
    [ElKoura, 2003]

- **Function of the hand**
  - Depends on object shape
  - Depends on intended action

[Cutkosky, 1986]
Related work – Virtual hands

- **Rigid proxies**
  - Simple simulation
  - Limited to abstract interaction

- **Articulated rigid hands**
  - Enable grasping
  - Only simulate hard contacts

- **Deformable models**
  - Realistic interaction
  - Higher computational cost

**Challenge 1**

Handling the many DoF of the hand

References:
- Boeck, 2004
- Craig, 2009
- Jacobs, 2011
- Talvas, 2015
- Borst, 2005
- Maciel, 2004
Related work – Haptic hardware

**Whole-hand**
- **Desktop**
  - Geomagic
- **Mobile**
  - Haption

**Multi-finger**
- [Monroy, 2008]

Challenge 2
Providing convincing haptic sensations
Related work – Passive and pseudo-haptics

- **Passive haptic feedback**
  - Real objects to provide haptic cues
  - Elastic input devices
  - Less flexible than active haptics

- **Pseudo-haptics** [Lécuyer, 2000]
  - Leverages the visual dominance on the perception of physical properties
  - For hand-based interaction: alter the motion of the user’s hand
**Objective**: Improve hand-based interaction in virtual environments

**Contributions**

**Axis I**: Improving the control of articulated hands

**Axis II**: Improving feedback with passive and pseudo-haptics

- **DoF reduction**
- **DoF separation**
- **Whole-hand**
- **Grasping**
- **Multi-finger**

- **DoF reduction**
- **DoF separation**
- **Passive**
- **Active**
- **Pseudo**

- **Virtual environment**

**Challenge 1**: Handling the many DoF of the hand

**Challenge 2**: Providing convincing haptic sensations

**User**
Axis I: Improving the control of articulated hands

DoF reduction  DoF separation
Contribution #1: THING

Axis I: Improving the control of articulated hands

DoF reduction
A multi-touch interaction technique for controlling 3D hand models

• **Approach**
  – **Reduce DoF** of hand models to couple them to **common input devices**

• **THING** *(in reference to the Addams Family character)*
  – Multi-touch control for animating hand models
  – Fingers animated via gestures on the tablet
  – Global position controlled via two variants, **mobile** and **desktop**
Animating the fingers

For each fingertip, $p_n = B(f_n) + a_n \cdot ((c_1 - b_1) \times (c_2 - b_2))$

Flexion

$\Delta f = |d_f| \cdot \text{sign}(d \cdot s) \cdot G(v_f)$

Adduction

$a = \text{sign}(d \cdot s^\perp) \cdot |d_a|$
Moving the hand: two variants

MobileTHING

- All DoF integrated on the tablet
- Move and tilt controls

DesktopTHING

- Position DoF delegated to traditional mouse controls
Example

- Integrated in the Blender 3D editor
- Animation produced in ~7 minutes
**Objective**
- Compare MobileTHING to traditional techniques of computer animation

**Task**
- Reproduce predefined postures

3 techniques × 4 poses × 5 repetitions × 12 participants

**Computer mouse**  **Data glove (mocap)**  **MobileTHING**
User study #1

- **Performance**
  - Glove and MobileTHING outperform Mouse

- **Subjective questionnaire**
  - No significant differences for MobileTHING in terms of ease, speed, comfort, fatigue
  - Glove did not fit 4 participants out of 16
User study #2

Objective
- Compare MobileTHING vs. DesktopTHING

3 techniques \( \times \) 3 poses \( \times \) 5 repetitions \( \times \) 12 participants

Performance
- Both THING variants outperform Mouse
- No differences between DesktopTHING and MobileTHING

Appreciation
- DesktopTHING for precision, fatigue
- Overall preference for DesktopTHING
THING: Multi-touch technique for manipulating 3D hand models

• **Common** low-cost input device

• The user’s gestures on the tablet are reflected on the hand models

• User studies
  – Performance similar to data glove, better than traditional computer mouse
  – Desktop version preferred over mobile variant, similar performance
Contribution #2: DesktopGlove

Axis I: Improving the control of articulated hands
Separating the DoF of virtual hands for haptic manipulation

- **Approach**
  - Separate DoF between two distinct interfaces

- **DesktopGlove**
  - Distribute the DoF of one virtual hand between both user’s hands
  - Global wrist control on one side, Local finger control on the other
**System**

**Global motion**

**Interface**  
Modified DigiHaptic [Casiez, 2003]

**Input**  
Finger flexion

**Output**  
Local grasping force

**Interface**  
Common haptic arm

**Input**  
Position and orientation

**Output**  
Global forces (collisions, weight)

**Local motion**
• **Pink arrows**: forces sent to the fingers (left hand)
• **Orange arrow**: force sent to the wrist (right hand)
Conclusion

**DesktopGlove**: Separate the degrees of freedom of one virtual hand between both user’s hands

- **Exhaustive haptic feedback** (local + global forces) with **accessible** interfaces

- User studies
  - Separated control: no significant negative effect on performance, preferred by users
  - Separated feedback: no significant negative effect
  - User preference:
    - global controls with dominant hand,
    - full force feedback on both hands
Axis I: Improving the control of articulated hands

DoF reduction  DoF separation
Axis II: Improving feedback with passive and pseudo-haptics

User

Interface

Haptic feedback

Virtual environment

Interaction technique

Whole-hand
Grasping
Multi-finger

Level of detail

Axis II: Improving feedback with passive and pseudo-haptics
Contribution #3: Elastic-Arm

Axis II: Improving feedback with passive and pseudo-haptics

Whole-hand
Human-scale haptic feedback for augmenting 3D interaction

• **Approach**
  – Leverage **passive components** to design **lightweight and mobile** haptic interfaces

• **Elastic-arm**
  – Elastic armature providing egocentric force feedback to the hand
  – Several interaction techniques based on a stretchable arm
System

- **Two states**
  - Relaxed (feedback on)
  - Extended (feedback off)

- **Main parameters**
  - Reach $r = h - s$
  - Rest length $d_e$
  - Max. extension $d_m$
Interacting through the Elastic-Arm

- Navigation
- Exploration
- Manipulation
Navigation

- **Stretchable arm to navigate towards out-of-reach objects**
  - *Go-Go*: extension of the user’s arm [Poupyrev, 1996]
  - *Bubble*: hybrid *position/rate control* [Dominjon, 2005]
• Simulate collisions with the Elastic-Arm

  - *Redirected touching*: warp virtual hand to simulate shapes [Kohli, 2010]
  - Match the rubber band extension with virtual collisions

\[ h_v = s + d_o \min(1, \frac{|r|}{d_e}) \]

Virtual hand position \( h_v \)

Distance to facing obstacle

Shoulder position \( d_o \)

\( s \)

\( r \)

\( d_e \)

= 1 when the cable is extended

Feedback

Collision!
Simulating different levels of effort with the Elastic-Arm

- Inspired by pseudo-haptic stiffness [Lécuyer, 2000]
- First, match the rubber band extension
- Then, scale the Control/Display ratio

\[ h_v = s + d_o \min(1, \frac{|r|}{d_e}) + \frac{|r| - d_e}{d_m - d_e} k \]

High \( k \) = low stiffness
Low \( k \) = high stiffness

Same as with redirected touching
Extension beyond rest length
Object-dependent Control/Display ratio
Alternative designs

Layers of stiffness

- Rubber bands with different lengths
- Each band matches a different event

Weight

- Rubber bands attached to the waist
- Pseudo-haptic simulation of weight
Conclusion

**Elastic-Arm:** Body-mounted armature providing egocentric force feedback to the user’s hand

Proposed 3D interaction techniques:

- Navigation/selection by **stretching the arm**
- Perceptual effects: **collisions** and **different levels of effort**
- Alternative designs: **layers of stiffness** and **weight**
Contribution #4 – The Virtual Mitten

Axis II: Improving feedback with passive and pseudo-haptics
Haptic manipulation of virtual objects using grip force

- **Approach**
  - Simulate grasping sensations with passive devices providing grip forces

- **Virtual mitten**
  - Real hands represented by simplified mittens
  - Elastic devices to control the mitten and deliver grip force
  - Visual feedback and pseudo-haptic effect to vary perceptions
System

Interface

Elastic device

Control scheme

Compression

\[ r \quad \begin{array}{c}
\text{Compression} \\
\end{array} \quad \begin{array}{c}
0 \\
\text{r}_{\text{folding}} \\
\text{r}_{\text{grasping}} \\
1
\end{array} \]
System

Feedback

Boolean

Progressive
**Objective:** simulate different levels of effort for different virtual objects

**Object A**

- \( r \) (0)
- \( r_{\text{folding}} \)
- \( r_{\text{grasping}} \) (1)

**Object B**

- \( r \) (0)
- \( r_{\text{folding}} \)
- \( r_{\text{grasping}} \) (1)
• Bimanual cooking scenario
• Stiffness of the fruits, weight of the glass, different interactive parts
**Objective**
- Evaluate if users can perceive levels of effort
- Compare *Boolean* and *Progressive* feedback

**Task**
- Perform various manipulation tasks with pairs of objects
  - « Which object required more effort? »

2 types of feedback $\times$ 4 tasks $\times$ 3 repetitions $\times$ 12 participants

**With Progressive feedback**
- Significantly more correct answers
- Compression applied closer to the grasping threshold

[Bloomfield, 2003]
User study #2

- **Objective**
  - Determine the resolution of the effect

- **Task**
  - *Rotating the cylinder* with the *Progressive* feedback

- **Just Noticeable Difference:**
  minimum difference between stimuli that can be discriminated

- **Four** different levels of effort
Multi-finger extension

- **ElasticGlove**
  - Modular passive exoskeleton
  - Constrains each finger individually

- **Pseudo-haptic simulation of heterogeneous materials**
  - Finger-specific Control/Display ratio
  - Haptic data embedded into mesh
Examples

Medical palpation

Piano Learning
Conclusion

**Virtual Mitten:** Interaction metaphor based on an elastic device

- **Lightweight elastic** input device
- Pseudo-haptic effect to simulate different levels of effort

- User studies
  - *Progressive* visual feedback provided better results
  - Can simulate up to 4 levels of effort

**ElasticGlove:** Extension to multi-finger interaction with passive exoskeleton
General conclusion

• **Objective**
  – Improve hand-based interaction in virtual environments

• **Contributions**
  – **Axis I:** Improving the control of articulated hand models
    • **DoF reduction** and multi-touch input
    • **DoF separation** between two haptic devices
  – **Axis II:** Combining passive and pseudo-haptics
    • Body-mounted elastic interface for **whole-hand** interaction
    • Elastic grip force device for simulating **grasping**
    • Passive exoskeleton for **multi-finger** manipulation
Future work

Axis I

- **Additional input to handle more DoF**
  - Force sensing for THING,
  - Greater number of fingers for DesktopGlove

- **Bimanual interaction**
  - Parallel hand animation for THING
  - Bimanual interaction techniques for DesktopGlove

Axis II

- **Low-cost tracking**
  - Pressure sensing for Virtual Mitten, bend sensing for ElasticGlove

- **Evaluate passive interfaces vs. active counterparts**
  - Elastic-Arm vs. Desktop interfaces
  - ElasticGlove vs. active exoskeletons
Perspectives

• **Software control of the missing DoF**
  – Inspiration from robotics (grasp planning), computer animation (shape matching, behavioral data)

• **Pseudo-haptic feedback for the simulation of complex sensations**
  – Multiple stimuli (multi-finger, bimanual)
  – Complex environments

• **Combining different haptic modalities**
  – Design a passive exoskeleton from passive components
  – Active/Passive/Crossmodal feedback combinations
Publications

• International conferences

• National conferences

• Submitted

• Patents
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Thank you for your attention