Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

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Audiovisual Experience

- Evolution of the audiovisual experience
  - Improving the Quality of Experience (QoE)
  - Focused on images and sound
  - Next step: sense of touch? (Haptic)

A trip to the moon. Méliès, 1902.
The jazz singer. Crosland, 1927.
The wizard of oz. Fleming, 1939.
Haptics and Audiovisuals

- Haptics already used in VR
- Early results on haptics for AV
  - Haptics may enrich user experience
    [O’Modhrain and Oakley 2003]
  - New medium to express content
    [Magnenat 2006]
  - New field of study: Haptic-AudioVisuals
    [El-Saddik 2007]

- How to augment audiovisuals with haptic feedback?
Challenges

How to design and add haptic effects to AV content?

How to integrate haptic effect into a film production workflow?

How to render haptic effects in video viewing settings?

How to evaluate the influence of haptic effects on the AV experience?
Workflow for adding haptic effects to audiovisuals

- Based on architecture for video streaming [Wu et al. 2001]
- Three steps
  - Production
  - Distribution
  - Rendering

[Workflow for adding haptic effects to audiovisuals]

Audiovisual media
Haptic effects

Production

Distribution

Container
Network

Encoder
Decoder

Rendering

Audiovisual renderer
Screen & Speakers
Haptic renderer
Haptic devices

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

[Danieau et al. 2013]
Outline

• State-of-the-Art of the Haptic-Audiovisuals
  – Production of haptic effects
  – Rendering of haptic effects

• Contributions
  – Production of haptic effects
  – Rendering of haptic effects

• Conclusion / Perspectives
Production of Haptic Effects

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience
Production of Haptic Effects

- **Capture devices**
  - Force sensors / Accelerometers
    - [MacLean 96]
    - [O’Modhrain and Oakley 2003]
    - [Brady et al. 2002]
  - Depth Camera / 3D trackers
    - [McDaniel et al. 2005]

- **Automatic extraction**
  - Visual / Audio
    - [Ur Rheman 2008]
    - [Rasool and Sourin 2011]
    - [Chi et al. 2008]
    - [Lee et al. 2013]
  - Metadata
    - [Yamaguchi et al. 2006]

- **Manual authoring**
  - [Enriquez and MacLean 2003]
  - [Gaw et al. 2006]
  - [Rahman et al. 2006]
  - [Ryu et al. 2008]
Production of Haptic Effects

• Capture devices
  – Force sensors / Accelerometers
    [MacLean 96]
    [O’Modhrain and Oakley 2003]
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  – Metadata
    [Yamaguchi et al. 2006]

• Manual authoring
  [Enriquez and MacLean 2003]
  [Gaw et al. 2006]
  [Rahman et al. 2006]
  [Ryu et al. 2008]
1. Creation of effects is difficult
   - Capture: synchronization between sensor and AV content
   - Automatic extraction: restricted to specific configurations
   - Manual: hard to design complex effects

2. Limited use of haptic effects in AV context
   - Only physical events

- Need for novel approach for producing haptic effects
- Explore the potential of haptics for AV
Rendering of Haptic Effects

Production

Haptic Authoring
- Capturing
- Automatic extraction
- Manual authoring

Audiovisual media

Haptic effects

Distribution

Container

Network

Rendering

Audiovisual renderer
Screen & Speakers

Haptic renderer
Haptic devices

Capturing
Automatic extraction
Manual authoring

Audiovisual media
Haptic effects

Container
Network

Audiovisual renderer
Screen & Speakers

Haptic renderer
Haptic devices
Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

Rendering of Haptic Effects

• Wearable devices
  – Vibrations
    [Lee et al. 2005]
    [Lemmens et al. 2009]

  ![Wearable devices with vibrations](image1)

• Handheld devices
  – Vibrations
    [Ur Rhéman et al. 2008]
  – Force-feedback
    [Yamaguchi et al. 2006]

  ![Handheld devices with vibrations and force-feedback](image2)

[3] Rhaman et al. 2010

[Lee et al. 2005]
[Lemmens et al. 2009]
[Ur Rhéman et al. 2008]
[Yamaguchi et al. 2006]
[Rhaman et al. 2010]
[Kim et al. 2010]
[Alexander et al. 2011]
[O’Modhrain and Oakley 2010]
Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

Rendering of Haptic Effects

• Desktop Devices
  – Force-feedback
    [Hoshi et al. 2010]
    [Gaw et al. 2006]
    [Kim et al. 2011]

• Haptic seats
  – Vibrations
    [Dijk et al. 2010]
    [Israr and Poupyrev 2011]
  – Motion
    [DBox]
1. Lack of devices adapted to a passive AV experience
   – Wearable / Handheld / Desktop: not adapted, weak effects
   – Seats: cumbersome, expensive

2. Few works on haptic rendering for HAV
   – Haptic effects designed for one specific device

• Need for dedicated haptic devices for AV settings
• Need for haptic rendering for HAV content
Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

Thesis Objectives

- Framework for producing haptic effects
- Haptic device for HAV
- Haptic rendering algorithm
- Haptic cinematography

Production

- Haptic Authoring
  - Capturing
  - Automatic extraction
  - Manual authoring
  - Haptic effects

Audiovisual media

Distribution

- Container
  - Network

Rendering

- Audiovisual renderer
  - Screen & Speakers
- Haptic renderer
  - Haptic devices
Contribution #1

Framework for producing haptic effects

- Haptic device for HAV
- Haptic rendering algorithm
- Haptic cinematography

Production

- Capturing
- Automatic extraction
- Manual authoring

Audiovisual media

Haptic effects

Distribution

Container

Network

Encoding

Decoding

Rendering

Audiovisual renderer

Screen & Speakers

Haptic devices

CONTRIBUTION TO THE STUDY OF HAPTIC FEEDBACK FOR IMPROVING THE AUDIOVISUAL EXPERIENCE
Current solution for producing haptic effects

- 3 different techniques

<table>
<thead>
<tr>
<th>Haptic Authoring</th>
<th>Audiovisual media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capturing</td>
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<td>Automatic extraction</td>
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<td>Manual authoring</td>
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</table>

- **Objective:** novel approach for producing effects
New framework for producing haptic effects

• Approach: combine the 3 techniques
New framework for producing haptic effects

• Proof-of-Concept
  – Capture of motion data
  – Manual edition thanks to force-feedback device
  – Automatic extraction of vibration effects
  – Preview of haptic effects
New framework for producing haptic effects

- Proof-of-Concept
  - Capture of motion data
  - Manual edition thanks to force-feedback device
  - Automatic extraction of vibration effects
  - Preview of haptic effects
PoC Details

• Capture device
  – Camera
  – IMU: linear acceleration (A)

• Preview of effects
  – Signal processing
    • Synchro with AV (haptic clap)
    • Low pass filtering
    • Gravity removal
  – Haptic Rendering

\[ F = kA \]

A = linear acceleration
k = scaling constant
Preliminary Conclusion

• Framework for producing haptic effects: **H-Studio**
  – Capture of motion data
  – Haptic preview of haptic effects

• User study
Contribution #2

Framework for producing haptic effects
Haptic device for HAV
Haptic rendering algorithm
Haptic cinematography
Existing solutions for simulating motion

- Sensation of motion in (home) cinemas
  - Simplified motion platforms
  - Force-feedback based (Haptic motion)
  - Vibration based
Existing solutions for simulating motion

Sensation of motion

Vibration-based

Haptic motion

Motion simulator

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience
• Sensation of motion induced by force-feedback embedded in a seat
  – Hands: haptic motion
  – Head: vestibular system
  $\rightarrow$ 6 DoF motion effect

• Suitable for consumer settings
HapSeat

• Video + Motion effects
  – Accelerations (a) + rotational speeds (w)
• How to render motion effects on the HapSeat?
  – Control model
• Physical Model
  – Reproduce acceleration felt by the moving actor
  → Compute acceleration for hands and head from global motion
HapSeat: Control Model #1

• Physical Model
  – Reproduce acceleration felt by the moving actor
  → Compute acceleration for hands and head from global motion
  – Example:

Motion data = left turn

HapSeat – Top View

User

G_{LA} G_{RA} G_{H}
• Physical Model
  – Reproduce acceleration felt by the moving actor
  → Compute acceleration for hands and head from global motion
  – Rigid Body Kinematics

\[
\overrightarrow{G_A G'_A} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} \left( a(t) + \frac{dw}{dt}(t) \wedge \overrightarrow{GP_A} + w(t) \wedge (w(t) \wedge \overrightarrow{GP_A}) \right)
\]

\( P_A = \) position of the body part (head, hand)
\( s_x, s_y, s_z = \) scaling factors
HapSeat: Control Model #2

• Geometrical Model
  – Reproduce position and posture of moving actor during recording
HapSeat: Control Model #2

- Geometrical Model
  - Reproduce position and posture of moving actor during recording

- Example

Motion data = left turn

HapSeat – Top View
HapSeat: Control Model #2

• Geometrical Model
  
  – Reproduce position and posture of moving actor during recording
  
  \[
  \overrightarrow{G_A G'_A} = f(\overrightarrow{T}, \overrightarrow{R})
  \]

  \[
  f(\overrightarrow{T}, \overrightarrow{R}) = \frac{\|\overrightarrow{T}\|T + \|\overrightarrow{R}\|R}{\|\overrightarrow{T}\| + \|\overrightarrow{R}\|}
  \]

  \[
  \overrightarrow{T} = \begin{bmatrix}
  s_x & 0 & 0 \\
  0 & s_y & 0 \\
  0 & 0 & s_z \\
  \end{bmatrix} a(t)
  \]

  \[
  \overrightarrow{R} = (R_x(m_x w_x(t)) R_y(m_y w_y(t)) R_z(m_z w_z(t))) - I_3 \overrightarrow{GP_A}
  \]

  \(P_A\) = position of the body part (head, hand)
  \(s_x, s_y, s_z, m_x, m_y, m_z\) = scaling factors
  \(I_3\) = Identity matrix
  \(R_x, R_y, R_z\) = rotation matrices
User Study

- **Objective:** study of the influence of the HapSeat on the QoE

- **Hypotheses**
  - HapSeat provides sensation of motion
  - HapSeat enhances quality of experience

- **Variables**
  - 2 videos + motion data
  - 4 haptic conditions
    - Physical Model, Geometrical Model, Random, None.

- **Measure**
  - QoE Questionnaire: Realism, Sensory, Satisfaction, Comfort

- **17 Participants**
  - Age: 36.1 (SD 11.1)

Video 1: real data  Video 2: synthetic data
User Study: Results

- **Statistical analysis**
  - Friedman anova
  - Wilcoxon tests

- **HapSeat enhances QoE**
  - Physical Model $\approx$ Geometrical Model
  - Random $\approx$ None
  - Realism, Sensory and Satisfaction factors improved
  - Comfort is constant

- **Discussion**
  - Comfort: head movement should be different than hands movement
  - No difference between models: need videos with more rotations
Preliminary Conclusion

• Haptic device for simulating 6DoF motion effects
  – HapSeat: 3 force-feedback devices
  – 2 control models: Physical and Geometrical

• User Study
  – Provides sensation of motion
  – Improves the video viewing experience
Contribution #3

- Framework for producing haptic effects
- Haptic device for HAV
- Haptic rendering algorithm
- Haptic cinematography

Diagram:

Production:
- Haptic Authoring
  - Capturing
  - Automatic extraction
  - Manual authoring
  - Haptic effects
  - Audiovisual media

Distribution:
- Container
  - Network

Rendering:
- Audiovisual renderer
  - Screen & Speakers
- Haptic renderer
  - Haptic devices

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience
HAV Rendering

- Objective: introduce haptic rendering for HAV
  - Multiple haptic effects, synchronized with AV content
  - Limited workspace of the haptic device
HAV Content

Example of video sequence composed of several shots

Movement toward the right | No effect | Movement toward the right | No effect | Movement toward the right | No effect
Motion rendering

• Control of motion platform
  – Washout filter: moves device under user’s perceptual threshold

  Movement toward the right  No effect  Movement toward the right  No effect  Movement toward the right  No effect

  washout filter  washout filter  washout filter  washout filter

– Perceptual threshold defined by the vestibular system [Nehaoua et al. 2008]
Haptic Rendering

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

Actuator positions

- Movement toward the right: No effect
- Movement toward the right: No effect
- Movement toward the right: No effect

Max
Min
Haptic Rendering

• Transitions between effects must be handled
  – Counter-effects
• Workspace of the actuator is underexploited
Haptic Rendering

- Transitions between effects must be handled
  - Counter-effects
- Workspace of the actuator is underexploited

- Washout filter not suitable for haptic rendering
  - Stimulate the kinesthetic system

- Washout filter for haptic rendering
  - User Body Model
  - Perceptive Optimizer
  - Workspace Optimizer
User Body Model

• Composed of segments and joints
  \[Schuenke\ et\ al.\ 2010\]

• Thresholds for kinesthetic perception
  • Angular speed of joints \[Jones\ 2000\]
  • Elbow: 1 deg.s\(^{-1}\); Neck, Shoulder: 0.5 deg.s\(^{-1}\)
Perceptive Optimizer

- Inverse Kinematics algorithm + User body model
- Limit speed $v$ of limb to value of thresholds
Perceptive Optimizer

- Inverse Kinematics algorithm + User body model
- Limit speed $\nu$ of limb to value of thresholds

$$
\nu = \arg\min (\|P(t - dt) + \nu \Delta t\|) \quad 0 \leq K(\nu, t)
$$

Diagram:
- $K(\nu, t): \nu$
- Inverse Kinematics
- Body model at instant $t$
- Limb speed amplitudes
- Perceptual Thresholds
- $\dot{\Theta}_{th}$
- $\Delta \dot{\Theta}_{th} = \dot{\Theta}_{th} - |\dot{\Theta}|$
- $K(\nu, t) = \min(\Delta \dot{\Theta}_{th})$
• Performs an offset to optimize the use of the workspace
• Rescales signal if workspace still not respected
Application to a real movie

- Movie: Sintel [Blender Foundation]
- Duration: 10 minutes
- Design: VFX Artist

Counter-effect without washout filter

“Imperceptible” counter-effect with washout filter
Preliminary Conclusion

• Haptic rendering integrating a washout filter
  – Model of user kinesthetic perception
  – Perceptive optimizer
  – Workspace optimizer

• Application to full video sequence

• User Study
  – Washout filter enhances QoE
Contribution #4

Framework for producing haptic effects
Haptic device for HAV
Haptic rendering algorithm
Haptic cinematography

Production

Haptic Authoring
- Capturing
- Automatic extraction
- Manual authoring

Audiovisual media
Haptic effects

Distribution
- Container
- Network

Encoding

Decoding

Rendering

Audiovisual renderer
Screen & Speakers

Haptic renderer
Haptic devices

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience
How to associate haptic effects to movies?

• Mainly used with action movies
  – Physical events: explosions, car chases, gun shots, etc.
  – Ex: movies proposed by D-Box

• Rarely used for enhanced drama, comedy, romantic movies
How to associate haptic effects to movies?

• Mainly used with action movies
  – Physical events: explosions, car chases, gun shots, etc.
  – Ex: movies proposed by D-Box

• Drama, comedy, romantic movies?
• Move beyond enhancement of only physical events
  → non-diegetic effects

Explicit Ills, 2008. Mark Webber
Taxonomy of Haptic Effects

- Diegetic
  - Haptic Effects
- Non-Diegetic

[Danieau et al. 2013b]
Cinematographic Camera Effects

• Camera Effects
  – Cinematic
  – Semantic

• Typical effects
  – Crane shot
  – Dutch Angle
  – Arcing
  – Traveling
  – Tilting
  – Zoom-in
  – Vertigo

[Mascelli. 1998]
[Thompson and Bowen. 2009]
Haptic Effects based on Camera Effects

- 2 control models
  - Cinematic
  - Semantic

- Proof-of-Concept
  - 7 Video Sequences
  - HapSeat
    - Cinematic model
    - Semantic model
Control Model #1: Cinematic

• Follows camera movement

Cinematic model with Arcing, Tilting and Zoom-in sequences
Control Model #1: Cinematic

- Follows camera movement
- Extension of Geometrical Model

\[
\overrightarrow{G_A G'_A} = f(\vec{T}, \vec{R})
\]

\[
f(\vec{T}, \vec{R}, \vec{Z}) = \frac{||\vec{T}||T + ||\vec{R}||R + ||\vec{Z}||Z}{||\vec{T}|| + ||\vec{R}|| + ||\vec{Z}||}
\]

\[
\vec{T} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} a(t)
\]

\[
\vec{R} = (R_x(m_xw_x(t)))R_y(m_yw_y(t))R_z(m_zw_z(t)) - I_3 \overrightarrow{GP_A}
\]

\[
\vec{Z} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & k_z \end{bmatrix} z(t)
\]

\(P_A = \text{position of the body part (head, hand)}\)
\(s_x, s_y, s_z, m_x, m_y, m_z, k_z = \text{scaling factors}\)
\(I_3 = \text{Identity matrix}\)
\(R_x, R_y, R_z = \text{rotation matrices}\)
Control Model #2: Semantic

• Based on the semantic of the Camera Effect
  – Crane Shot → Flying away
  – Dutch Angle → Instability
  – Arcing → Intensification
  – Traveling → Crab Walk
  – Tilting → Inferiority
  – Zoom-in → Walk forward
  – Vertigo → Vertigo

• Designed with our authoring tool
User Study

• Objective: study of the influence of the haptic effects based on camera motions on the QoE

• Hypothesis
  – New haptic effects increases QoE

• Variables
  – 7 video sequences
  – 4 haptic conditions
    • Cinematic, Semantic, Random and None

• Measure
  – Pairwise comparison (78 couples)
  – Score computed for each model

• 38 Participants
  – Age: 36.3 (SD 10.4)
User Study: Results

• Statistical analysis
  – Friedman anova
  – Wilcoxon tests

• Haptic effects enhance QoE
  – Cinematic > Semantic ≈ None > Random
  – Semantic > None
    • Vertigo
    • Arcing
    • Tilting

• Discussion
  – Metaphors well understood
  – Dynamics of haptic feedback should be similar to dynamics AV content
Application to real movies

Big Buck Bunny

Sintel

Tears of Steel
Preliminary Conclusion

• Haptic Cinematography
  – Taxonomy of haptic effects
  – Haptic effects based on camera motions

• User study
  – Cinematic model enhances QoE
  – Semantic model works on particular cases

• Application to real movies

Big Buck Bunny
Sintel
Tears of Steel
Conclusion

• Study of haptic feedback for AV content

Framework for creating haptic effects
  – Capture, automatic, manual and preview

Hand Haptic device for enriching the AV experience
  – 6DoF sensation of motion based on force-feedbacks

Gear Haptic Rendering for HAV
  – Washout filter for kinesthetic perception

Film Haptic Cinematography
  – Haptic effects based on cinematographic camera motions

• User studies
  – First guidelines for designing haptic effects
Conclusion
Short-term perspectives

• H-Studio
  – Comparison editing methods: usability studies
  – Automatic extraction of motion effects

• HapSeat
  – Improve sensation of motion: more points of stimulation
  – Improve comfort: different rendering for head and hands

• Washout filter
  – Enhance workspace optimizer: limit rescaling
  – Improve user model: user’s attention

• Haptic Cinematography
  – Exploring the taxonomy of haptic effects
  – Combination of diegetic and non-diegetic effects
Long-term perspectives

• Production
  – Create numerous haptic sensations (pressure, temperature, etc.)
  – Edit complex haptic effects (explosion = vibrations + temperature + motion)
• Rendering
  – Hardware: render multiple sensations (vibrations + temperature + motions + etc.), full-body experience
  – Software: adapt haptic effects to any end-devices
• Distribution
  – Contribution to standard (ex: MPEG-V)
• User Experience
  – Objective evaluation of the user experience (biosignals)
  – Model of the user HAV experience
Publications

• Journals


• Conferences


Publications

• Patents

• Demo / Posters
Thank you! Questions?

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

Publications
• Journals: IEEE ToH (x2), IEEE Multimedia.
• Conferences: IEEE Haptics Symposium, ACM VRST.
• Patents (x3)
• Demos: ACM SIGGRAPH ET, ACM CHI, ACM UIST.

Feedback from SIGGRAPH and CHI demos
HapSeat: workflow

SIMULATION

Video
Motion Data

\[ a(t), w(t) \]

WORKFLOW

Model

Haptic Rendering

\[ G'_A, F_A \]

DEVICES

\[ G_{HA}, G_{LA}, G_{RA} \]

Screen
HapSeat: Haptic Rendering

• Output of Model = Positions
• Novint Falcons are impedance devices
  – Output = force
• Pseudo-Position control using spring-damper model

\[ F_A = k (G'_A - P_A) dV_A \]

\( G'_A \) = target position
\( P_A \) = current position
\( k \) = spring constant
\( d \) = damping constant
Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

- Washout filter added to the workflow
  - Optimize positions computed by control model
- 3 main components
  - User Body Model
  - Perceptive Optimizer
  - Workspace Optimizer
User Study: Questionnaire

• Background
  • Presence: feeling to be physically situated in a virtual environment [Witmer 1998]
  • Usability: how a system is to use [ISO 9241-11]

• Questions associated to factors
  • 7 questions evaluated on 5-point scale

• Presence
  • Control
  • Sensory
  • Realism
  • Distraction

• Usability
  • Efficiency
  • Effectiveness
  • Satisfaction

• HAV QoE
  • Sensory
  • Realism
  • Satisfaction
  • Comfort
<table>
<thead>
<tr>
<th>Factor</th>
<th>Question</th>
</tr>
</thead>
</table>
| Realism    | • How much did this experience seem consistent with your real-world experiences?  
              • How strong was your feeling of self-motion?                        |
| Sensory    | • How much did the haptic feedback contribute to the immersion?        
              • Were the haptic and visual feedback synchronized together?       |
| Comfort    | • Was the system comfortable?                                          
              • How distracting was the control mechanism?                      |
| Satisfaction| • How much did you enjoy using the system?                              |
Objective: Study of the captured motion effect

Hypotheses
- Motion effect increases QoE
- Motion effect is realistic

Experimental Plan
- 15 participants. Age: 27.8 (SD 9.7)
- 4 videos and 3 haptic feedback
  - None, Random, Realistic
- Protocol: QoE Questionnaire
  - Realism, Sensory, Comfort, Satisfaction

Results
- QoE Real > QoE Random > QoE None
- Realism, Sensory and Satisfaction improved by haptic feedback
- Comfort is stable

![User Study](chart.png)
Washout Filter for Haptic Rendering

- Thresholds for kinesthetic perception
  - Angular speed of joints [Jones 2000]
  - 3 profiles

<table>
<thead>
<tr>
<th></th>
<th>Threshold (deg.s(^{-1}))</th>
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<tbody>
<tr>
<td>T1 [Jones 2000]</td>
<td>Neck, Shoulder, Elbow 0.5; 0.5; 1</td>
</tr>
<tr>
<td></td>
<td>Neck; Shoulder; Elbow 1.5; 1.5; 2.5</td>
</tr>
<tr>
<td></td>
<td>Neck; Shoulder; Elbow 3; 3; 4</td>
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</tbody>
</table>

- User body model
  - Used to model user’s perception
  - Composed by segments and joints [Schuenke et al. 2010]
User Study

• Objective: study of the influence of the washout filter on the QoE

• Hypotheses
  – Counter-effects must be not perceived
  – Washout filter enhances QoE

• Variables
  – 3 videos: 3, 4 and 5 haptic effects
  – 4 haptic feedback:
    • T0 (no Washout Filter),
    • T1, T2 and T3 (Washout Filter with different thresholds)

• 20 Participants
  – Age 39.7 (SD 9.2)

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<tr>
<td>T2</td>
<td>Threshold (deg.s(^{-1}))</td>
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<tr>
<td>Neck; Shoulder; Elbow</td>
<td>1.5; 1.5; 2.5</td>
</tr>
<tr>
<td>T3</td>
<td>Threshold (deg.s(^{-1}))</td>
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<tr>
<td>Neck; Shoulder; Elbow</td>
<td>3; 3; 4</td>
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</table>
User Study: Results

- Washout filter improves QoE
  - $T_0 > T_1$, $T_2$ and $T_3$ (low rank is the best)
  - No difference observed between thresholds

- 3 groups observed during experiment
  - Found with hierarchical cluster analysis

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<table>
<thead>
<tr>
<th>Rank</th>
<th>T0</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
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<td>0.5</td>
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</tbody>
</table>
```

![Cluster Analysis Diagram]
User Study: Results

- **Washout filter improves QoE**
  - $T_0 > T_1, T_2$ and $T_3$ (low rank is the best)
  - No difference observed between thresholds

- **3 groups observed during experiment**
  - Found with hierarchical cluster analysis
  - Group 1: $T_1 < T_2 < T_3$
  - Group 2: no preference
  - Group 3: $T_2 < T_1$ and $T_3$
Guidelines for designing Haptic Effects

• Synchronization
  – Ex: random feedback, counter-effects

• Dynamics
  – Ex: semantic model

• AV defines context
  – Ex: semantic model

• Haptic / Audiovisuals combinations
  – Taxonomy

• Need for user studies to identify more rules
• Need to organize these rules