sensory expansion
exploring human sensory potential in 3D interaction

Dr. Ernst Kruijff
Institute of Visual Computing
3DMi group
Bonn-Rhein-Sieg University of Applied Sciences

who am I?

- senior researcher at Institute of Visual Computing
- 28+ researchers
- Bonn-Rhein-Sieg University of Applied Sciences
- head of 3DMI Group (~4 RAs)
- focus on 3DUI design, human factors, multisensory interfaces
- backtracking to 1998
  - CURE, TU Graz / ICG, Fraunhofer IMK/IAIS, Bauhaus-University Weimar

potential of the human body

control potential

© youtube
250* Meisner and Merkel receptors per cm² in dermis acuity of up to 0.5 mm*

*various studies

Humans have amazing capabilities
what will I talk about?

- expanding sensory feedback in VR/AR/mobile through human potential driven interface design
- approach
- interface case studies:
  - vision in wide FOV displays (AR)
  - touch/haptics for handheld devices (AR/mobile)
  - audio-tactile 3D glove interface (VR/AR)
  - multisensory feedback for installations (VR/AR)

...and what not?

- specific user-dependant issues
  - different users, different potential
- I generalize
- details on control of applications
- social boundaries

design premises

- deploy abilities of human body to receive information or perform actions considering all sensorimotor and non-physical human control systems
- frequently used method: sensory and control substitution
  - think out of the box in alternatives
  - focus in this talk: sensory systems

References
- Beckhaus, S., Kruijff, E. Unconventional Human-Computer Interface. ACM SIGGRAPH 2004 course notes
reasons and applicability

why?
- performance
- attractiveness, “user experience”

where?
- improve ad-hoc or purely experimental design processes
- mobile, AR or VR projects

design process

human factors driven iterative design process
- perform user and task analysis
- analyze
  - analyse sensory potential: features and intensity
  - analyse control potential: task syntax, capabilities of human body
- design (alternative) techniques
- evaluate and reflect performance
  - often energetic principles need to be regarded (workload, attention)

alternatively: study first, then design!

sensory potential

- cortical homunculus
- different parts of body have different “sensitivity”

isn’t this just multimodal interfaces?

- maybe
  - sensory expansion can focus on the simultaneous stimulation of multiple senses
- no
  - the expansion may also incur within a single sensory system
  - the design process is different: potential driven instead of “just adding a second sensory channel”
human robot?
- yes, kind of:
  - seeing a human being as a set of input (sensor) and output (control) parameters

slide “logic”
- (psycho-)physiological aspects
- targeted potential, design goals and approach
- design and implementation
- validation
- reflection and lessons learned

expanding: visual wide field of view AR displays

psycho-physiology: peripheral vision
- retinal anatomy
  - fovea: 5.2°
  - parafovea: 5-9°
  - perifovea: 9-17°
  - peripheral vision*: 17°-180°
- sensitivity and attention
  - low visual acuity and colour perception, but sensitive to motion

*different definitions of peripheral vision are used throughout literature
psycho-physiology: pre-attentive objects

- basic visual features are pre-processed before actual attention is placed
  - feature integration theory used for addressing attention
  - "bundle of shapes"


design goals and approach

potential: use peripheral vision to perceive (additional) content

- create effective view management
- visibility/legibility of augmentations should depend on areas in the retina
- "decompress" potentially dense information by expanding visual field, use borders for less important info

→ however, guidelines are hardly available!

experiments

goal
study the effects of wide field-of-view (FOV)

factors:
- sensitivity of the eyes
  - attention, noticeability
  - visibility/legibility
- search “behaviour”
- cognitive load

Reference: Kiyokawa, K., Naohiro Kishishita, Jason Orlosky (Osaka University)
**Hyperboloidal Head Mounted Display**
- wide FOV optical see-thru HMD
  - maximum field of view: \( \approx 109.5^\circ \times 66.6^\circ \)
  - Luminance: up to 60.2 cd/m\(^2\)
- Android-phone for position and orientation measurement

Reference:

**In-view vs. in-situ labelling**
- **In-view labelling**
  - always appear within the view
  - appear on its border with a leader line if the referenced object is outside the view
  - higher label density!
- **In-situ labelling**
  - appear only if the referenced object is within the view without a leader line, as if it is affixed to the referenced object

**Experimental Task**
- **Use divided attention task**
- such tasks are commonly found in outdoor (head-worn) AR
  - **Primary task in the real environment**
    - walking down to the station
    - browsing the web on the phone at a traffic light
    - talking to a friend
  - **Secondary task in the augmentations**
    - following a label to find a shop

Reference:
Grasset et al. (2011)

**Experiment #1**
- subjects solve a Sudoku puzzle for maximum five minutes twice outdoor
- during the session, 10 red boxes (4.6\(^\circ\) x 9.2\(^\circ\)) always appear whereas a white label appears for 10 seconds at 10 random timings
- following the label, subjects find and keep the referenced box within a 10\(^\circ\) x 10\(^\circ\) aiming box on the HMD screen for 2 seconds, or they fail
conditions experiment #1

- a within-subject, 2x4 factorial design
  - 2 labelling techniques: in-view and in-situ
  - 4 conditions for the FOV: 36º, 54º, 81º and 100º of horizontal FOV
  - 16 subjects (8 male, 8 female, mean age 23.4)
  - Latin square distribution
  - measured data
    - discovery rate, response time and Sudoku solving time, head rotation, mental workload

results experiment #1

search performance

- FOV affects search performance in AR
  - a wider FOV decreases the performance with in-view labelling (Type A)
  - a wider FOV increases the performance with in-situ labelling (Type B)
  - performance with in-view always better than that with in-situ, with a suggested convergence at around 130º of FOV
  - results in line with expectations

mental workload

- FOV does not affect mental workload in AR
  - FOV does not impact self-reported mental workload
  - FOV does not impact ease of noticing annotations, or concentration on Sudoku task, even though discovery rates dramatically change
  - results not in line with expectations
  - more details in IEEE ISMAR 2014 paper

results experiment #1

same setup as experiment #1

- 16 (8m, 8f) subjects walk along a predefined route back and forth for +/- five minutes
- 18 objects always appear around subjects
- in 9 of 14 'zones', one object turns a target
- subjects need to follow the label to find targets

experiment #2
results experiment #2

- evaluating the effort of wide FOV see-through HMD on information receptive outdoors with HHMPD
  - little effort
  - it is effective to present information on peripheral vision (by FOV at 100 degrees) in addition to central vision
  - in-view decreases, in-situ increases, overlap at 100 degrees
  - no significant effect of FOV on workload

reflection: expanding visual field

- studies seem to correlate quite well
- wide FOV (till 100 degrees) can be used at “no cost” with respect to cognitive load
- search effectiveness drops at borders, but, this also depends on label method

next step: label visibility/legibility in wide FOV displays (controlled environment)

expanding: touch/force

- flexible surfaces for mobile displays

physiology: finger touch/force

- fingers: mainly affected by somatosensory system
  - mechanoreceptor: vibrations, pressure, and texture
  - thermoreceptor
  - nocireceptor
  - proprioception
design goals and approach

potential: make use of fine finger sensing capabilities to interact with display content in quasi-3D

- interact with flexible (instead of rigid) surfaces
- create novel kinds of physical feedback on mobile devices for games, modelling/painting, etc.

approach

- create "second skin" for displays
  - allow for finger/pen vertical displacement and adjustment of surface tension
- related approaches: flexible screens, vibration, foils

design and implementation: first version

- adjust rubber surface tension (force/displacement) using servo (Phidgets)
- "membrane" speaker: surface vibrates on sound
- circular touch

feeling audio?

- modulate tactor speed based on audio wave form
  - wave amplitude=speed
- previous experiment: texture recognition in an audio-tactile setup

second version

- semi transparent silicon over tablet display and loudspeaker
- visible screen content
- surface tension driven by three servos
- darker=higher tension
- pen
- Unity3D implementation

reflection: expanding touch through audio-tactile “skin”

- physical displacement of pen due to single direction stretching
- interesting effect with potential
  - finger is better than pen tip
- improvements needed:
  - back to multi-direction stretch
  - different pen, finger support
  - faster servos
  - validation

expanding: touch / audio-tactile audio-tactile glove for 3D manipulation
**physiology: tactile / proprioception**

similarities to flex surface physiology
- particularly interested in mechano and proprioceptors
- receptors in dermis: vibrations, rotational movement of limbs, stretching of skin
- muscle spindles, tendon connection to bone: bodily configuration, for example grasp

**design goals and approach**

**potential:** combined processing of stimuli
- support fine grain interaction with occluded objects
- reduce erroneous selection and manipulation caused by overshooting

**design goals and approach**

**method**
- combination of proximity and collision feedback
- adjust ballistic phase of motion
- combine vibration with audio

\[\text{quasi substitution of proximity information through combined processing of stimuli}\]

**design and implementation: first version**
- micro-vibrators at thumb, index finger, palm of hand
- loudspeaker at palm
  - “car navigation” sound: just distance
- Unity3D, Arduino and Leap motion
  - Leap = unreliable first implementation
- screen-based application
- cheap alternative to cyberglove

*together with Eduard Assenheimer, Alexander Marquardt, Andre Hinkeljann*
validation / exploratory study

study to inform design process
key-lock type task
9 subjects, 36 trials per subject

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Summary table performance time in seconds. T1 is object selection, T2 is object placement.

design and implementation: second version

- micro-vibrators at other three fingers, around wrist
- proximity: adjustment of audio-only to combination of audio + vibration at wrist
- deal with proximity direction
- improved hand tracking
  - new Leap implementation in Unity much more reliable

reflection: expanding touch through audio

- proximity provides useful cue to adjust ballistic phase
  - avoid overshooting
  - needs further balance between audio/vibration
- learning effects expected
  - “inverse” feedback in case of second version
- just VR?
  - lightweight version for wearable AR
expanding: multisensory
multisensory interfaces for the age of the Rift

psycho-physiology: multisensory
- complex area, interplay between all sensory systems not always well understood
- multisensory binding theory: interplay between systems
  - bias, enrichment, transfer

psycho-physiology: balancing stimuli
- effort: perceive stimulus and trigger appropriate output
  - informational quality, cognitive load
  - intensity depends on user, task, environment
  - sensory blocking, impairment
  - gaming experience (!)

design goals and approach
potential: stimulate full body / most senses
- create sensory rich, engaging experience
- trigger different emotional reactions
design goals and approach

- many different multisensory systems
  - but lack of “ground truth”
  - and/or many trade secrets (theme parks)
- try to quantify effect of different stimuli on emotion
  - quasi recipe: two pinches of stimuli x + a spoon of stimuli y = emotion z

Together with Alexander Marquardt, Christina Trepkowski, Andre Hinkelmann

design and implementation: poor man’s visuals

design and implementation: audio/haptics

- headphones for normal audio
- low frequency audio (subwoofer)
  - 600W, 100L box
  - capable of > 15hz
- bass-shaker
  - capable of > 1hz
- both operated at > 20Hz

→ body haptics

body haptics/resonance experiment

- initial experiment:
  - 32 users, between subjects
  - different frequencies indeed result in different haptic sensation
  - peaks between different frequencies and body parts are too narrow with current setup (next slide)
brief summary validation

notes:
no shift in Hz per body part, just strongest body vibration, no effect of audio on/off
study continues using other methods

vibration patterns back of user

design and implementation: tactile
- ventilators (200 m³/h)
- tactile grid mounted on chair (10 micro-vibrators)
  - Arduino-driven
  - follows system idea from Israr & Poupyrev

design and implementation: olfaction
- various versions based on a miniature smoke generator
- triggered by Arduino
- room for improvement

Reference:
design and implementation: complete

- Unity3D and Uniduino
- keyboard and gamepad
- 3 games
  - racer
  - Tuscany
  - don’t let go

validation

- 20 (male) users ($M=24.65$, $SD=3.54$)
  - mostly daily (45%) or weekly gamers (45%)
- 6 “emotionally loaded” situations
  - The uncomfortable demo: spiders, bees, ...
  - The speed demo: racing through bad weather, danger from behind
  - The turning bad demo: Tuscany demo extended with Zombies
- 5-7 minutes per game
- stimuli adjusted to situations
  - patterns for back-vibration, ...

questionnaires

- emotion per situation
- influence of stimuli on emotion/situation
- igroup presence questionnaire (IPQ)

(difficult) goal: quantify effect of stimuli on emotions

subjective emotional rating up to medium (~3.5 out of 5)

- some significant effect of stimuli on emotion, for example:
  - zombies: sound, gfx
  - Tuscany: wind, smell
validation

- IPQ analysis
  - reasonable level of presence and involvement, but could/should be higher
  - realism scores very mediocre: low resolution of Rift DK1 disappointed many users

- Noticeable degradation / negative effect of low resolution of HMD
  - high fidelity likely increases presence, engagement, and usability

reflection

- lessons learned
  - statistics do not always match observational data
    - (male) users may have difficulties “expressing emotions”
  - “sensory adaptation”: gamers are used to more extreme stimuli and are not easily satisfied
    - most extreme stimuli (bass/vibration) scored best
    - subtle stimuli → over-amplify stimuli

- Noticeable degradation / negative effect of low resolution of HMD
  - high fidelity likely increases presence, engagement, and usability

Reference:
reflection

- quantification of effect of stimuli is hard
  - effect can hardly be isolated
  - design of stimuli is currently rule of thumb
- next experiments
  - higher user diversity, larger group (32+)
  - closely look at arousal
  - future: coupling with biosensors

next steps: WIP

- maximization and over-amplification
  - interaction space
    - full walking in place (2 x 2 x 2.5m “CAVE”)
    - rigged chair
    - full tracking
  - visual
    - improved resolution (DK2)
  - auditory
    - add spatial audio (mainly for observer)
  - body-haptics
    - experiment with body worn devices
  - wind
    - larger fans (10x throughput, heat)
  - smell
    - ultrasonic evaporation
- miniaturization
  - wearable setup to be connected to AR experience

conclusion

the bumpy road ahead
meta-reflection

- looking at the potential of the human body can yield experimental but highly interesting interfaces
- human-factors studies often look at limitations, looking at potential is much more fun!
- validating can be challenging, isolation of factors often hard

meta-reflection

- still, validation is the key to a better understanding
  - consider: study first, then design (instead of vice-versa)
  - longitudinal studies / effects
  - benchmarks will likely become crucial

sensory potential is vast
don’t be afraid to use it

(and I did not even focus on control potential)

thanks
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more info: ernstkruijff.com

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