sensory expansion

exploring human sensory potential in 3D interaction

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Visual Computing

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

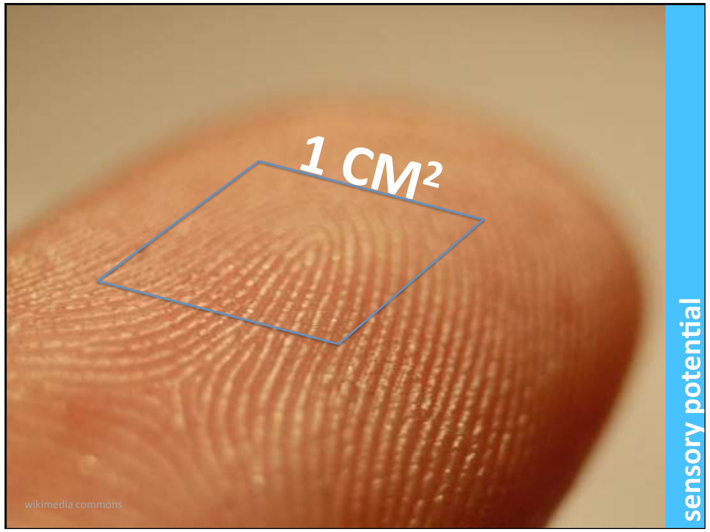
→ ivc.h-brs.de

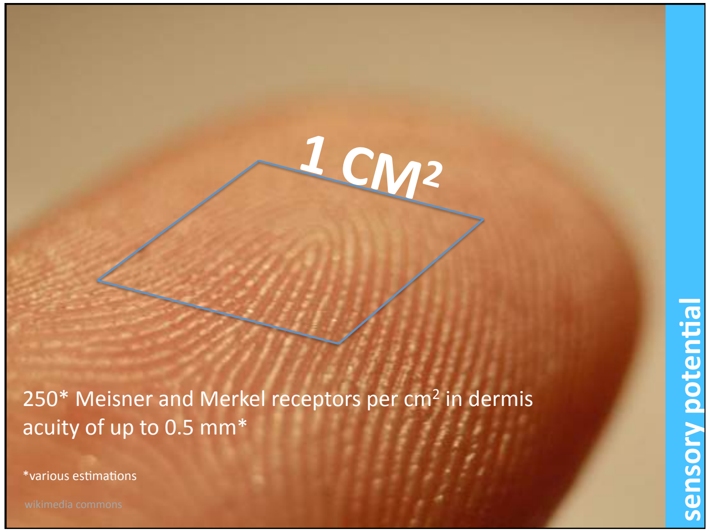
→ ernstkruijff.com

qualcomm augmented reality lecture series

potential of the human body

control potential





humans have

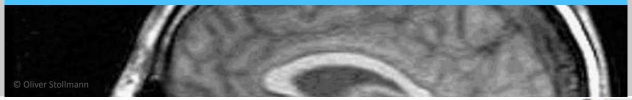
AMAZI NG CAPAB ILITIES

what will I talk about?

QUALCOMM AR Lecture Series

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)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...and what not?

specific user-dependant issues
- different users, different potential
- → I generalize

details on control of applications

social boundaries

- **expanding sensory feedback**

  human potential driven design principles

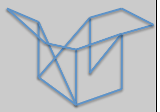
design premises

- 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
Kruijff, E. Human-potential Driven Design of 3D User Interfaces. Proceedings of the IEEE International Conference on Artificial Reality and Telexistence (ICAT 2013). Tokyo, Japan, 2013.

Beckhaus, S., Kruijff, E. Unconventional Human-Computer Interfaces. 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

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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!

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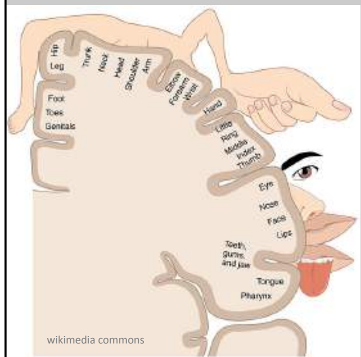
sensory potential



- cortical homunculus
- different parts of body have different "sensitivity"

Reference
W. Penfield and T. Rasmussen, *The Cerebral Cortex of man - a Clinical Study of Localization of Function*. New York: The Macmillan Comp., 1950.

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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"

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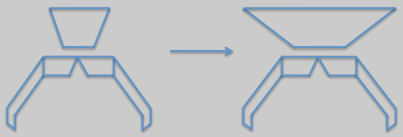
human robot?

- yes, kind of:
  - seeing a human being as a set of input (sensor) and output (control) parameters

slide "logic"

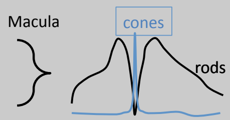
- (psycho-)physiological aspects
- targeted potential, design goals and approach
- design and implementation
- validation
- reflection and lessons learned

- **expanding: visual**
  wide field of view AR displays



psycho-physiolology: 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”

Reference
Treisman, A., and G. Gelade (1980). "A feature-integration theory of attention." Cognitive Psychology, Vol. 12, No. 1, pp. 97–136.

object → pre-attentive state (analyse object) → focussed attention state (combine features) → perception

design goals and approach

potential: use peripheral vision to perceive (additional) content


Entrance by AOL, copyright AOL.

- create effective view management
  - visibility/legibility of augmentations should depend on areas in the retina
  - “decompress” potentially dense information by <u>expanding visual field,</u> 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

experiments

- divided attention tests
  - outdoor/sitting
  - outdoor/walking
- (visibility/legibility test)

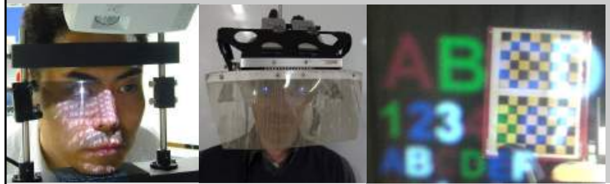

Qualcomm talk
Kiyoshi Kiyokawa, Designing, Implementing and Evaluating Wide-view Optical See-through Head Mounted Displays

together with Kiyoshi Kiyokawa, Naohiro Kishishita, Jason Orlosky (Osaka University)

hyperboloidal Head Mounted Display

- wide FOV optical see-thru HMD
  - maximum field of view : ~109.5º x 66.6º
  - Luminance : up to 60.2 cd/m^2
- Android-phone for position and orientation measurement

Reference
D. Nguyen, T. Mashita, K. Kiyokawa, and H. Takemura, "Subjective Image Quality Assessment of a Wide-view Head Mounted Projective Display with a Semi-transparent Retroreflective Screen," in Proceedings of the 21st International Conference on Artificial Reality and Telexistence (ICAT 2011), 2011.



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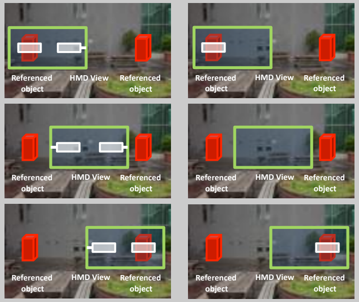
in-view vs. in-situ labelling

- **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



in-view labelling | **in-situ** labelling

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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

Grasset et al. (2012)

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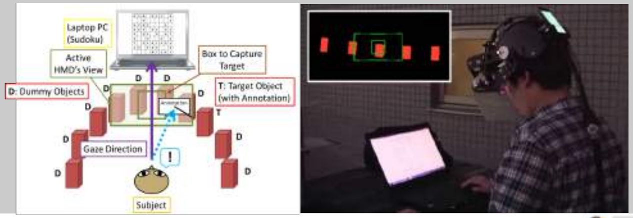
experiment #1

- subjects solve a Sudoku puzzle for maximum five minutes twice outdoor
- during the session, 10 red boxes (4.6º x 9.2º) 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 10º x 10º aiming box on the HMD screen for 2 seconds, or they fail



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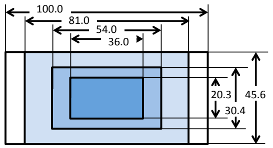
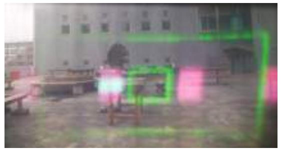
conditions experiment #1

- 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 Suzoku 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

results experiment #1

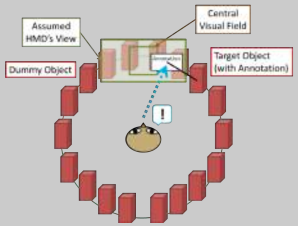
mental workload

- 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

Kishishita, N., Kiyokawa, K., Kruijff, E., Orlosky, J., Mashita, T., Takemura, H. Analysing the Effects of a Wide Field of View Augmented Reality Display on Search Performance in Divided Attention Tasks. In Proceedings of the IEEE International Symposium on Mixed and Augmented Reality (ISMAR'14), Munchen, Germany, 2014.

experiment #2



- 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

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

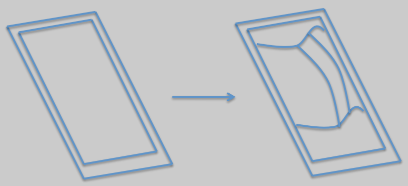
reflection: expanding visual field

- 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)

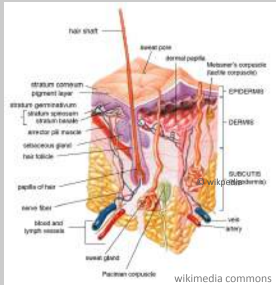
- **expanding: touch/force**

  flexible surfaces for mobile displays



physiology: finger touch/force

- fingers: mainly affected by somatosensory system
  - mechanoreceptor: vibrations, pressure, and texture
  - thermoreceptor
  - nociceptor
  - proprioception



wikimedia commons

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.

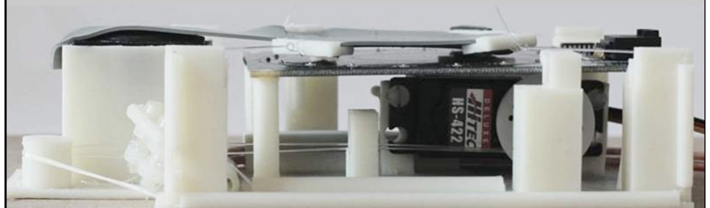
design goals and approach

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?

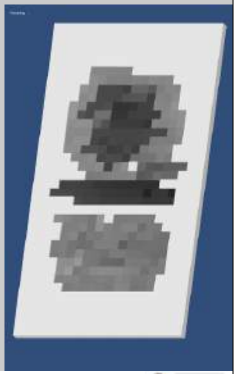
- modulate tactor speed based on audio wave form
  - wave amplitude=speed
- previous experiment: texture recognition in an audio-tactile setup

Reference:
Kruijff, E. et al. 2006. Tactylus, a Pen-Input Device exploring Audiotactile Sensory Binding. Proceedings of the ACM Symposium on Virtual Reality Software & Technology 2006 (2006).

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

together with Saugata Biswas, Niranjan Deshpande



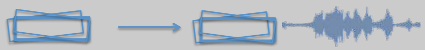
video second version

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

© Ori jane

design goals and approach

method

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

→ quasi substitution of proximity information through combined processing of stimuli

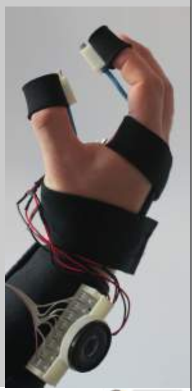
© cyberglove systems

© Ori jane

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

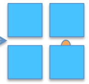
together with Eduard Assenheimer, Alexander Marquardt, Andre Hinkenjann



validation / exploratory study

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

different margins
occluded object



mar gin		Visual T1	Visual T2	Σ	Tactile T1	Tactile T2	Σ
7	*avg*	15.23	6.99	22.22	11.37	4.68	16.05
	stdev	22.25	7.92	30.17	8.60	2.89	11.49
16	*avg*	8.20	5.83	14.03	6.58	4.95	11.53
	stdev	12.00	4.33	16.33	5.17	4.07	9.24
25	*avg*	6.72	4.52	11.42	6.48	5.54	12.02
	stdev	5.65	2.99	8.64	4.37	5.35	9.72

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

validation

	avg	stdev
fatigue	4.67	2.06
comfort	5.00	1.87
usefulness audio/proximity	4.78	1.92
usefulness vibration	6.33	1.41
able to recognize shape and size	5.33	2.12
feeling of grabbing real object	4.00	2.06
difficulty occlusions	3.33	1.66
overall rating	5.44	1.51

Summary of results questionnaires (7 point Likert scale)

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

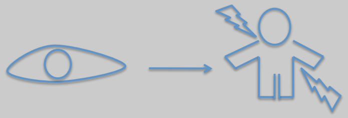
micro-vibrators turned outwards for illustrative purposes

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

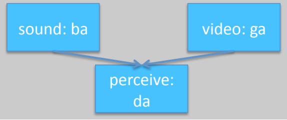
- **expanding: multisensory**

  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



Reference: S. Shimojo and L. Shams, "Sensory Modalities are not Separate Modalities: Plasticity and Interactions," *Curr. Opin. Neurobiol.*, vol. 11, pp. 505–509, 2001.

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 (!)

Reference: J. Loomis, "Sensory Replacement and Sensory Substitution: Overview and Prospects for the Future," in in *Converging technologies for improving human performance*, M. Roco and W. Bainbridge, Eds. Kluwer Academic Publishers, 2003.

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

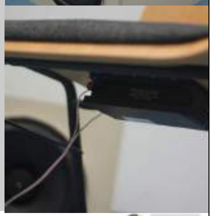
together with Alexander Marquardt, Christina Trepkowski, Andre Hinkenjann

design and implementation: poor man's visuals

design and implementation: audio/haptics

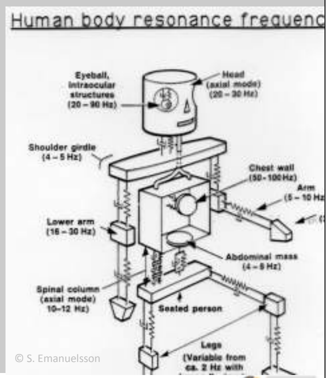
- headphones for normal audio
- low frequency audio (subwoofer)
  - 600W, 100L box
  - capable of > 15hz
- bass-shaker
  - capable of > 1hz
- both operated at > 20Hz

→ body haptics

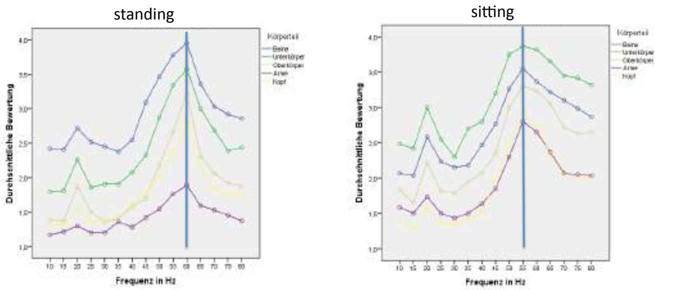


body haptics/resonance experiment

- 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)



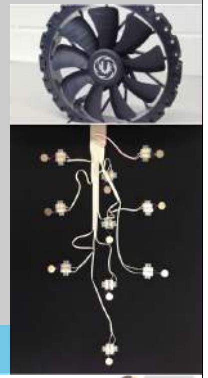
brief summary validation



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

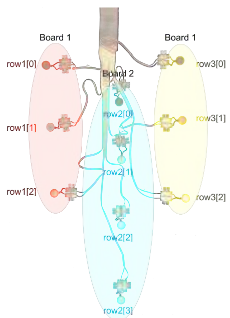
design and implementation: tactile

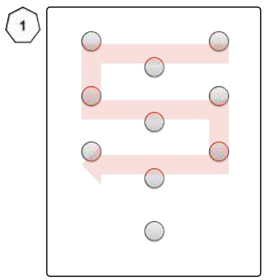
- ventilators (200 m^3/h)
- tactile grid mounted on chair (10 micro-vibrators)
  - Arduino-driven
  - follows system idea from Israr & Poupyrev



Reference:
Israr, A., Poupyrev, et al., Surround Haptics: Sending shivers down your spine. SIGGRAPH Conference Abstracts and Applications, Emerging Technologies, 2011

vibration patterns back of user





design and implementation: olfaction

- various versions based on a miniature smoke generator
- triggered by Arduino
- room for improvement

design and implementation: complete

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

© Unity, Yorick van Vliet

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, …

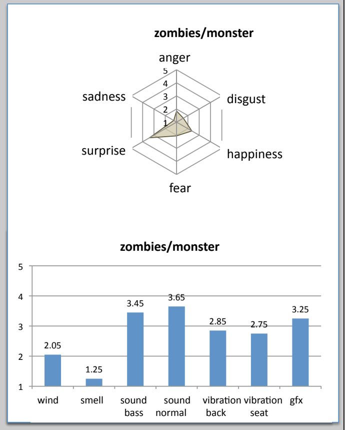
validation

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

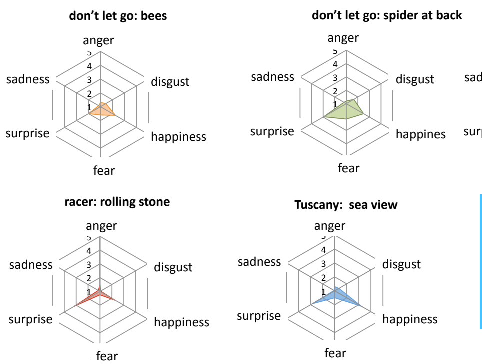
(difficult) goal: quantify effect of stimuli on emotions

validation

- 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



often only few or one main axis = goal mostly achieved

complete isolation will be very hard

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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

Mean	Spider	Race	Tuscany	Maximum
Presence	6,20	5,35	6,50	10
Involvement	10,05	10,65	11,55	15
Realism	5,75	5,75	5,60	10

Visual Computing

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 → <u>over-amplify stimuli</u>

Visual Computing

reflection

lessons learned

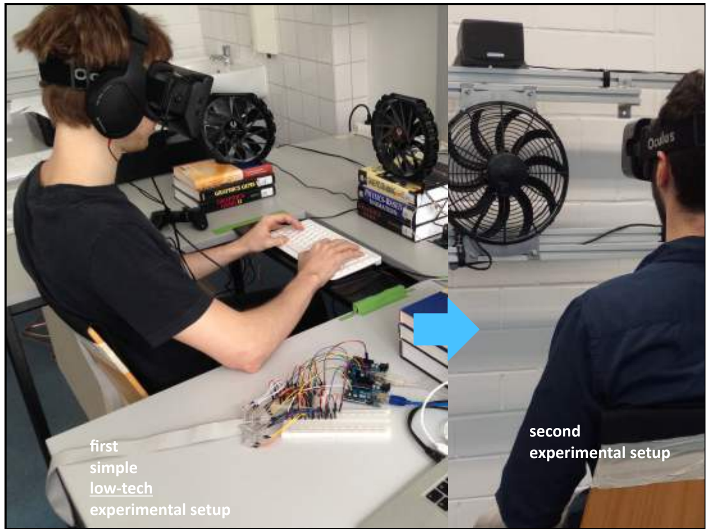
- noticeable degradation / negative effect of low resolution of HMD
  - high fidelity likely increases presence, engagement, and usability

Reference: McMahan et al. Evaluating Display Fidelity and Interaction Fidelity in a Virtual Reality Game. IEEE TVCG 18,4, 2012

Visual Computing

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

Visual Computing

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

Visual Computing

sensory potential is

vast

don't be afraid to use it

(and I did not even focus on control potential)

youtube

thanks

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more info: ernstkruijff.com

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