Physiological computing reshapes user-system interaction research and its practical application

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PRESENTATION OVERVIEW

- Introduction
- User-system interaction
- Physiological computing trends
- Multimodal data integration
- Practical examples
- Conclusions
LUCAS NOLDUS

- M.Sc. Leiden University, The Netherlands (biology)
- Ph.D. Wageningen University, The Netherlands (behavioral ecology)
- Founder and Managing Director, Noldus Information Technology
- Research Associate, Wageningen University & Research
- Chairman, ICT for Brain, Body & Behavior Foundation
- Secretary, Man-Machine Interaction Platform
- Secretary for International Affairs, Netherlands Academy of Technology and Innovation
NOLDUS INFORMATION TECHNOLOGY

Software for human-system interaction research and UX testing

Integrated measurement and analysis systems, UX labs

Training, consultancy
NOLDUS INFORMATION TECHNOLOGY

FOUNDED IN 1989 BY LUCAS NOLDUS

160 NOLDUS EMPLOYEES IN 9 COUNTRIES

OVER 9700 CUSTOMERS IN 98 COUNTRIES
CUSTOMERS

SOME OF OUR USERS
PRESENTATION OVERVIEW

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THE USER IN THE CENTER

- Guiding principle for development of interactive systems
- From initial brainstorms to usability and UX testing
- Iterative process
HUMAN FACTORS RESEARCH IN AVIATION

- Early adopters of physiological computing in system development (1980s)
- Mission-critical systems: avionics, cockpits, air traffic control systems
- Eye tracking, heart rate, EEG
SOFTWARE DEVELOPMENT IN THE 1990s

- Context of use: office
- Goal: automating routine tasks, maximizing productivity
- Hardware: desktop computer
- User testing = assessment of **usability**
  - Efficacy (success rate)
  - Efficiency (time on task, error rate)
  - User satisfaction (subjective)
- Techniques: observation, note taking, video annotation, counting mouse clicks

*Schusteritsch et al. (2007)*
SOFTWARE DEVELOPMENT IN 2018

- Context of use: office, home, car, anywhere!
- Goal: business, commerce, communication, social media, entertainment, anything!
- Hardware platforms: desktop computers, notebooks, tablets, smartphones, smart watches
- Different operating systems, web browsers
- Accessibility and privacy legislation
- Multiple countries and cultures
USER RESEARCH AND TESTING

From design to deployment

- Observe user behavior
- Test usability and UX

Agile / Scrum
FROM USABILITY TO USER EXPERIENCE

Usability

- Efficacy
- Efficiency
- User satisfaction

User Experience (UX)

- Usability, plus:
- Engagement
- Trust
- Cognitive workload
- Excitement
- Fun
- Etc.
TOOLS FOR UX RESEARCH AND TESTING

- Video and audio recording
- Event logging tools
- Keystroke and mouse click loggers
- Eye trackers
- Physiology equipment
- Facial expression analysis tools
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- **Physiological computing trends**
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PHYSIOLOGICAL COMPUTING TRENDS

Technical trends
- Smaller sensors
- Wireless sensors
- More processing power
- More bandwidth

Implications
- Less obtrusive measurements
- From the lab to naturalistic settings
- Higher ecological validity
- From post-hoc analysis to real-time monitoring, feedback and intervention
CARDIAC ACTIVITY

- **Heart rate (HR):** heartbeat frequency as beats per minute (bpm)
- **Heartbeat (R-R interval):** time between consecutive heartbeats (R-waves) in milliseconds (ms)
- **Heart rate variability (HRV):** beat-to-beat variation in the time between consecutive R-R intervals
AUTONOMIC NERVOUS SYSTEM

Sympathetic nervous system
- Speeds up bodily functions
  - Heart rate ↗
  - Heart rate variability ↓
- Stress reactions

Parasympathetic nervous system
- Calms down bodily functions
  - Heart rate ↓
  - Heart rate variability ↑
- Recovery
HEART RATE MEASUREMENT
REMOTE PHOTO-PLETHYSMOGRAPHY

- Blood pressure pulses
- Changes in blood volume
- Small changes in facial skin color
- Signal in sync with heart rate
- Measure stress level, cognitive workload

McDuff (2015)
REMOTE PHOTOPLETHYSMOGRAPHY

FaceReader
Now: heart rate
Next step: heart rate variability (requires higher sampling rate)
EYE TRACKING

Readouts
- Gaze direction
- Eye movement (fixations, saccades)
- Pupil dilation (mental workload)
- Blink rate (fatigue)
Automatic analysis of facial expression

- Six basic facial expressions
- Valence and arousal
- Facial action units
- Affective states
- Real-time analysis
- Basic emotions ("big 6" + contempt)
- Facial state (eyes, mouth, eyebrows)
- Head orientation, gaze direction
- Action units
- Analyze affective attitudes: 'boredom', 'interest', and 'confusion'.
FACEREADE: AFFECTIVE ATTITUDES
FACEREADER

- Analyze expressions under challenging circumstances (e.g. partial occlusion)
- Uses deep learning (Deep Face Model)
Analysis of infrared images / video
ADD FACE READING TO MOBILE APPS

- FaceReader SDK for Android (try it now!)
- SDKs for Linux and iOS to follow later
BRAIN ACTIVITY

- Electro encephalography (EEG)
- Near infrared spectroscopy (NIRS)
- Correlations have been found between:
  - Power in specific bands of EEG spectrum and well-controlled computer tasks
  - Patterns in EEG signal and hedonic valuation of food
- Popular application: “neuromarketing” (scientific validity is debated)
- Movement artefacts: limited use outside laboratory
- No consensus about applicability in UX research and product design
BRAIN ACTIVITY

ELECTROENCEPHALOGRAPHY
NEAR INFRARED SPECTROSCOPY (NIRS)
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MULTIMODAL MEASUREMENT

- Many sensors to choose from, but which is right one to measure a specific aspect of user-system interaction?

- One sensor is often not enough!
  - Koldijk et al. (2014): ECG, EDA, facial expression, body posture, key strokes → facial expression correlated most strongly with mental workload
  - Hogervorst et al. (2014): EEG, EDA, respiration, ECG, pupil size, eye blinks → EEG correlated best with mental workload, eye-related measures came next

- Data from one sensor may be ambiguous (e.g. eye tracking)

- Interpretation of signal may depend on context (e.g. facial expression)

- Needed: multimodal measurement and analysis
MEANING OF FACIAL EXPRESSIONS

In HCI context:

- **interest/vigilance**
- **focus/concentration**
MULTIMODAL MEASUREMENT: CHALLENGES

- Connecting all components
- Interoperability
- Data synchronization
- Real-time monitoring and diagnostics
- Offline data integration
The Observer XT can integrate and synchronize data from many different sources.
DATA COMMUNICATION AND SYNCHRONIZATION

- Simulator or real car
- Eye tracking system
- Physiological measures
- Emotion recognition
- Video and audio
- Data platform: The Observer XT
- N-View: Visualization dashboard

N-Linx Server

N-Linx Plugin
MULTIMODAL DATA INTEGRATION

EXAMPLE: VIDEO + ECG

CONNECTION SCHEME
MULTIMODAL DATA INTEGRATION

The Observer XT
REAL-TIME MULTIMODAL DATA VISUALIZATION
## MULTIMODAL ANALYSIS

### Data Analysis

![Data Analysis Diagram]

<table>
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<tr>
<th>Statistics</th>
<th>Behaviors</th>
<th>Modifiers</th>
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<tr>
<td></td>
<td>Disgusted Intensity</td>
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</tr>
</tbody>
</table>
MULTIMODAL ANALYSIS

Combining eye tracking and face reading data

EYE TRACKING ALONE

AVAILABLE RESULTS:

Where are they Looking
- Level of Attention
- Ignoring or not finding
- Distraction
MULTIMODAL ANALYSIS

Combining eye tracking and face reading data

Available results:

Where are they Looking
- Level of attention
- Ignoring or not finding
- Distraction

EYE TRACKING ALONE

Available results:

Where are they Looking
- Level of attention
- Ignoring / finding
- Distraction

Emotional & Cognitive Reaction while Looking
- Level of happiness
- Level of frustration
- Level of confusion
- Amount of cognitive load being exerted by the user

Purple: Positive valence
Red: Negative valence
MULTIMODAL ANALYSIS

FROM SENSOR DATA TO COGNITIVE STATE

Measuring the cognitive human

Research agenda for the practical application of cognitive human factors

Authors: Rolf Zon (NLR), Kees Nieuwenhuis (Thales Netherlands), Peter Renden (VU and HHIS), Colin Guiling (MARIN), Jan van Erp (TNO) - 20 March 2018
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HILAS - Human Factors Integration in the Lifecycle of Aviation Systems

Generic Research Aircraft Cockpit Environment (GRACE), National Aerospace Laboratory, Amsterdam
Multimodal analysis of pilot-system interaction and communication

- Multiple synced videos
- Video control
- Various speeds
- Hairline: ‘You are here’
- Signals (physiology, simulator, CAN bus, etc.)
- Event Log (behaviors, eye tracking areas of interest)
- Synchronized view of all data!
Usability testing of avionics systems

GE Haptic display mount in GRACE flight simulator
Objectives

- Measurements of situational awareness and fatigue
- Prototype testing

Facilities

- Multiple flight simulators
- Two eye trackers
- Physiological data acquisition
- The Observer XT software + custom extensions
Boeing Helicopter Simulator Lab

Boeing AH-64 D/E Apache

**Measurement modalities**

- 2x video with gaze overlay (and audio)
- 2x video
- Gaze events (raw and fixations)
- Blink events
- Simulator parameters
- Time-stamped markers and comments
Boeing Helicopter Simulator Lab

Boeing AH-64 D/E Apache
Boeing AH-64 D/E Apache
COMMERCIAL AIRCRAFT CORPORATION OF CHINA

Tools
- Video + audio
- Multi-camera eye tracking
- Facial expression analysis
- Physiology (ECG, EDA, EMG, respiration)
- Finger tracking
- Event logging
DRIVER-VEHICLE INTERACTION

- Cars are invaded by interactive digital devices
- Driver-vehicle interaction becomes more intensive
- Risk of information overload and distraction
- Research on adaptive information systems and other driver support systems
MULTIMODAL DATA INTEGRATION

Connections
- Data – NCF
- Video – IP
- Audio – analog
- Measurement

WIVV computer
Smart eye Computer
TMSi Computer

Simulator
Eye Tracking
Psycho Physiology

Mic
Cameras
The Observer XT
N-Linx server
N-View

ET events
ET data
Sim events
Sim data
Events + data
Events + data
Events + data

ET data
Phy data

DriveLab in action
REAL-TIME MULTIMODAL MONITORING

**N-View data visualization**

- Data from different instruments in a single display
- User-defined dashboards
- Data transmission via IP networks
- Runs on PC, notebook, tablet and smartphone
EYE TRACKING OF MOVING OBJECTS

Communication between eye tracker, data integration software (The Observer XT) and car simulator:

1. The Observer XT asks eye tracker “what does the respondent look at?”
2. The eye tracker responds with gaze coordinates
3. The Observer XT asks simulator “which object is displayed at these coordinates?”
4. The simulator responds with the name of the object at those coordinates

This is a unique feature in DriveLab: automatic registration of eye fixation on static and moving objects – no more manual labeling!
**Project:** Advanced Driver-Vehicle Interface in a Complex Environment (ADVICE)
TRUCK SIMULATOR

- PC setup for:
  - Visuals
  - Other traffic
- Most relevant driving tasks are pre-defined
- Realistic scenarios:
  - Other traffic (cars, pedestrians, etc.)
  - Signage (traffic lights, signs, etc.)
  - Weather conditions
- Physics engine (part of Unity simulation environment) provides real-life vehicle handling
- Scenarios can be custom developed

Research objectives
- Improve product design and evaluation
- Increase traffic safety
- Investigate the human factor in driving
- Human-in-the-loop testing
User Experience testing at Wargaming.net

Tools
- Video + audio
- Eye tracking
- Physiology (ECG, EDA, pulse)
- Event logging

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More

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User Experience testing at Rabobank

Tools
- Video + audio
- Eye tracking
- Event logging
Facilities for physiological and behavioral computing: critical success factors

- **Flexibility**: new tools and changing needs will force change
- **Scalability**: allow growth and addition of new tools
- Automatic *synchronization* of all data collected in integrated system
- **Live data integration**: prevent post-hoc data transfer
- **Offline data integration**: should also be possible
- **Interoperability**: use N-Linx for communication between systems
- **Data types**: support all standard data types
INNOVATION = COLLABORATION

TECHNOLOGY PROVIDERS
- SMEs developing
- Sensors
- Actuators
- Data acquisition systems
- Computer vision systems
- Data analysis software
- Test apparatus

Role in i3B
- Technical research
- Product development

FIELD LABS
- Example domains
  - Consumer lifestyle
  - Intelligent lighting
  - Eating behavior
  - Sports
  - Psychiatric disorders
  - Ambient assisted living
  - Security/forensics

Role in i3B
- Testing in real-life context
- Scientific validation
- Practical validation
- Clinical validation

i3B Lab
- Collaborative R&D
- Co-design
- System integration
- Functional testing
- Technical validation

END USERS
- Consumers
- Patients
- Hospitals
- Universities

Consulting firms
- Automotive industry
- Aerospace industry
- Pharma Industry

Role in i3B
- Food industry
- Plant breeding industry
- Animal production industry
- Large-scale deployment
- Practical use

KNOWLEDGE PROVIDERS
- Universities
- Research institutes

Role in i3B
- Scientific research
- Technical research
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CONCLUSIONS

- Physiological computing tools offer us a glimpse in the user’s physical, mental or emotional state
- Plus: great level of detail, reliable, objective and automated
- Wide availability of sensors for physiological and behavioral measurement
- Abundance of low-cost computing power
- Exciting new avenues for design of products and services that are safer, easier and more pleasant to use!
THANK YOU FOR YOUR ATTENTION

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