Eye Tracking and Gaze-based Interaction
Introduction and Current Research Trends

Human-Computer Interaction 2 - 10.01.2018

WS 2017/2018
New Interaction Methods are Desirable

The amount of interaction with computer devices increases.

Consequently we look for interaction methods which are:

- quicker
- do not require training
- do not need physical and mental efforts

Eye tracking is a promising technology as the eyes are quick and we use them with ease.
Things We Can Do with Eye Tracking

Text 2.0

A project from DFKI (German Research Center for Artificial Intelligence)
A Smart Computer Needs Awareness for Gaze

Eye gaze is very important for human-human interaction

... and human-computer interaction should be like human-human interaction.

Taken from Milekic: The More You Look the More You Get: Intention-based Interface using Gaze-tracking
What the Eyes Can Tell

- Eyes indicate visual interest
- Gaze precedes actions
- Eyes reflect cognitive processes
- Eyes reflect physical and mental condition

In HCI Gaze Can Be

- A source of information about the user
- An input method

Eye trackers keep advancing and getting cheaper!
Expectations for Eye Gaze Interaction

**Hopes**
- Ease of use
- Speed up interaction
- Maintenance free
- Hygienic interface
- Remote control
- Safer interaction
- Smarter interaction

**Fears**
- Ability to control the eyes
- Conflict of input and vision
- Fatigue of eye muscles

As eye movements are part of our social protocol we are able to control our eyes.

Normally we look at the interaction element for input.

Our eyes move constantly even if we sleep.
Eye Tracking Applications
Eye Tracking Applications

Gaze-supported (Multimodal) Interaction

Explicit gaze-based Interaction

Implicit gaze-based Interaction

Gaze Monitoring

Gaze Monitoring

- Collect data about the user
  - Cognitive load
  - User’s attention
  - Visual preference
Gaze Monitoring

Studying visual attention

People do notice the displays

Nicholas S. et al. (CHI 2015)
Gaze Monitoring

Support in collaborative environments

Akkil et al. (CHI 2016)
Gaze Monitoring

Optimizing Interfaces
Implicit gaze-based Interaction

Detecting intention/need for assistance

Walber et al. (CHI 2014)

Karolus et al. (CHI 2017)
Implicit gaze-based Interaction

Gaze-assisted Photo/Video editing

Santella et al. (CHI 2006)

We record gaze data from viewers on the original widescreen video. (Each viewer is marked in a different color.)

A cut from the woman’s face to the man’s face

The cropping window pans to the left while zooming in.

Jain et al. (ACM Trans. Graph. 34, 2015)
Gaze-supported (Multimodal) Interaction

- Combine gaze with other input modalities, such as
  - Touch
  - Mid-air gestures
  - Pen-input, Phone-input, etc..

Chatterjee et al. (ICMI 2015)
Khamis et al. (CHI 2016)
Kumar et al. (CHI 2007)
Gaze-supported (Multimodal) Interaction

We combine gaze with multi-touch for...

... implicit mode-switching.

Pfeuffer et al. (UIST 2014)
Gaze-supported (Multimodal) Interaction

Stellmach et al. (CHI 2013)
Explicit gaze-based interaction

- Using eyes for input/control
  - Moving the mouse
  - Selection
  - Scrolling
  - Eye typing
  - Authentication

Gaze-based authentication
EyePassShapes - De Luca et al. (SOUPS 2009)

Eye-based interaction with displays - Zhang et al. (UbiComp 2013)

Gaze input for the disabled

Source:
Explicit gaze-based interaction

In this interface, overlaid orbits with clockwise movement raise the volume or skip to the next song.

Esteves et al. (UIST 2015)
Explicit gaze-based interaction

Spontaneous Interaction with Displays

Zhang et al. (CHI 2013)
Explicit gaze-based interaction

Manual And Gaze Input Cascaded (MAGIC) pointing

1. The user gazes at the target

2. The cursor is wrapped to the eye tracking position

3. The distance to target is significantly shorter despite the tracker’s accuracy limitations

Zhai et al., (CHI 1999)
How Does Eye Tracking Work?
Eye Anatomy
The Human Eye - Movement Control

Images from:
https://droualb.faculty.mjc.edu/Lecture%20Notes/Unit%203/muscles%20with%20figures.htm and https://de.wikipedia.org/wiki/Augenmuskeln#Entwicklungsgeschichte
The Human Eye - Vision

The eye works similar to a camera.

However there are some differences:

- For adjusting the focus the lens changes its form (and not the position)
- The sensor surface is curved (and not plane)
- The sensor resolution is higher in the central field of vision (and not uniform)

From Duchowski, T. D.: Eye Tracking Methodology: Theory and Practice
Types of Eye Movement
The Human Eye - “Movement Types”

- **Fixations**
  - (mostly) stable eye position

- **Saccades, Microsaccades**
  - fast „ballistic“ eye movements

- **(Smooth) Pursuit**
  - following an object with your eyes
  - cannot be done voluntarily

- **Vestibulo-ocular Reflex**
  - compensate head movements

- **Optokinetic Nystagmus**
  - combination of pursuit and saccades

- **Vergence Movements**
  - Cooperation of both eyes to focus a single object

- **Pupil Dilation**
  - diameter change due lighting conditions, increased cognitive load
Fixations

- A pause, usually between 200 and 600 ms
- Humans fixate to sharply focus on a narrow area, long enough for the brain to perceive it
- Visualization as heat map

http://www.prweb.com/releases/2005/03/prweb213516.htm
Fixations - Interaction example

- One possible interaction using fixations is the dwell time method

  Typical application: Eye typing for handicapped (since the 80ies)
  Problem: Midas Touch effect, slow

- Another interaction using fixations is multimodal interaction - fixate and press key
  Problem: Need of second modality, not contact-free, but quickest interaction method

https://www.youtube.com/watch?v=oXBKXRqxVnU
Saccades

- Fast jumps from a fixation point to another
Saccades - Interaction Examples

- **Gaze gestures**

  Looking at the corners of the screen in a certain order

  ![Diagram](image)

- **Reading detection, activity recognition**

  A series of forward saccades and a long backward saccade indicate reading activity.
Smooth Pursuits

- Smoothly follow a moving target

https://www.andreas-bulling.de/fileadmin/docs/vidal13_ubicomp.pdf
Interaction using Smooth Pursuits

Orbits works by correlating the positions of all orbits on-screen with the user’s gaze.
Vestibulo-ocular Reflex

- Compensation of head movements

https://www.youtube.com/watch?v=j_R0LcPnZ_w

Interaction method using the vestibulo-ocular reflex: gaze-based head gestures
Optokinetic Nystagmus

- Smoothly follow a moving target

Vergence Movements

- Cooperation of both eyes to focus a single object

Florian Alt, Stefan Schneegass, Jonas Auda, Rufat Rzayev, and Nora Broy. 2014. Using eye-tracking to support interaction with layered 3D interfaces on stereoscopic displays. IUI '14
Pupil Dilation

- Change in diameter to accommodate lighting
  - circular muscles around the pupil

- (Smaller) change in diameter when exerting mental effort
  - radial muscles around the pupil
  - used to estimate cognitive/mental workload

Bastian Pfleging, Drea K. Fekety, Albrecht Schmidt, Andrew L. Kun, A Model Relating Pupil Diameter to Mental Workload and Lighting Conditions in Proc CHI `16
Eye Tracking Technologies
Eye Tracking Technologies

Remote Eye Tracking

Head Mounted Eye Tracking

Tobii eye trackers

Pupil labs eye tracker
# Eye Tracking Technologies

<table>
<thead>
<tr>
<th></th>
<th>Remote Eye Trackers</th>
<th>Head Mounted Eye Trackers</th>
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</thead>
<tbody>
<tr>
<td>Tracks gaze..</td>
<td>on displays</td>
<td>in natural settings</td>
</tr>
<tr>
<td>Building responsive systems requires...</td>
<td>developing a software using an SDK</td>
<td>labeling the surroundings (e.g. adding QR-codes to products)</td>
</tr>
<tr>
<td>Setup</td>
<td>Easy to setup</td>
<td>Cumbersome to wear</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Allows very limited movements</td>
<td>Allows free head/body movements</td>
</tr>
<tr>
<td>Can users see the gaze data?</td>
<td>Yes</td>
<td>No, unless you provide the user with another display</td>
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http://www.useeye.de/  

http://www.research-results.de/
Eye Tracking Producers

Open Source

(a)

(b)

Open Eyes project
http://thirtysixthspan.com/openEyes/

Commercial

Tobii Glasses 2
Wearable eye tracking
Second generation

Pupil Eye Tracker (open source software)
Eye Tracking Techniques
Eye Tracking Techniques

- Video-based Tracking
- Infrared Pupil-Corneal Reflection (IR-PCR) Tracking
- Electrooculography-Based (EOG) Tracking

EOG Goggles

IR-PCR Eye trackers

Tobii Glasses Eye tracker

Tobii Eye Tracker (stationary)
Eye Tracking techniques - Video-based

- Can be remote or head-mounted
- Relies on image processing
  - Pupil detection (SET, Starburst algorithms)
- Accuracy/quality is influenced by:
  - camera parameters (distance, resolution, ...)
  - lighting conditions
  - reflections of glasses/lenses, obstacles (eyelids)

Eye Tracking techniques - IR-PCR

- Can be remote or head-mounted
- “Corneal reflection” serves as static reference point
  - Allows slight head movement
  - More accurate gaze data
- Does not work outside (sunlight)
Eye Tracking techniques - EOG

- Uses electrodes attached on the skin
- Can work in complete dark settings (e.g. closed eyes)
- Signal processing is computationally lightweight
- It can be affected by signal noise (e.g. power line)
- Less accurate, even with medical-grade equipment
Challenges
Challenges

Interaction

● Midas touch (Perception vs Interaction)
● Involuntary eye movements

Data Interpretation

● Gaze fixation point != Visual attention
● Experiment Bias
● Eye Fatigue

Technical

● Accuracy
● Calibration
● Environmental Artefacts
● Sampling Rates
Midas Touch

Should the class end earlier?

Accidently choosing “No” while reading (Midas Touch)
Involuntary eye movements

In other words:
What is relevant data and what is not?
Data Interpretation

Gaze fixation point $\neq$ Visual attention

Humans are not necessarily paying attention to what they look at
Data Interpretation

Eye fatigue

Kosch et al. (CHI 2018)
Accuracy

Visual angle

http://www.cns.nyu.edu/~david/courses/perception/lecturenotes/eye/eye.html
Environmental Artefacts

- Makeup
- Interference (e.g. electromagnetic)
- Lighting conditions
Calibration
Calibration
Calibration

+ Results in more accurate data.
- Difficult and tedious.
- Might break if a user moves.
- Almost impossible to determine the exact pixel a user is gazing at.
Calibration-free Eye Tracking
Calibration-free eye tracking

Smooth Pursuits
(Vidal et al. UIST 2013)

SideWays
(Zhang et al. CHI 2013)
Calibration-free eye tracking

Nagamatsu et al. PerDis 2014

Drewes et al. 2007
(can also be done without calibration)
Take-home Messages

Gaze is a promising modality

- for understanding the user
- for interacting with computers and smart environments
- when combined with other modalities

Gaze technologies still have some limitations

- Require calibration (low usability)
- Track one user at a time
- Can be confused with perception (Midas touch)
- Not flexible for dynamic environments (e.g. public displays)
Our Research Interests
Gaze-based Interaction on Public Displays
Challenges of Gaze-based Interaction with Large Public Displays

1. Position

2. Movement

3. Calibration
EyeScout: Active Eye Tracking for Position and Movement Independent Gaze Interaction with Large Public Displays.

Project by Alexander Klimczack and Martin Reiss
GazeDrone: Using Drones as Mobile Remote Eye Trackers for Public Displays

Project by Anna Kienle
Text-based Calibration of Eye Trackers

Project by Ozan Saltuk
Text-based Calibration of Eye Trackers
Our Research Interests

Proficiency Awareness through Gaze Features