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Report about the Selected Tracking Technologies and Sensor Integrations

Easy Reading

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Executive Summary

This deliverable gives a short overview of the state of the art in user tracking by discussing a few examples of existing systems for web tracking (Google Analytics) and emotion detection (Face Reader, EQ Radio). It then gives an overview of existing related EU funded research, also giving an “Of interest rating” from the view of the Easy Reading project.

The following chapters discuss several kinds of potentially useful data that might give indication of a user’s cognitive load and emotional state. These include Galvanic Skin Response (GSR), Heart Rate Variability (HRV), Eye-Tracking and Mouse-Tracking, as well as facial expressions.

Finally, the deliverable discusses which sensors have been selected for usage in Easy Reading and gives the reasons for these decisions.

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Table of Content

Introduction - what is user tracking?

The most common understanding of the term "user tracking" is the tracking of the users' behaviour on a website, mainly for the purpose of marketing. Wikipedia defines website user tracking as follows:

"Website visitor tracking (WVT) is an aspect of Web analytics and deals with the analysis of visitor behaviour on a website. Analysis of an individual visitor's behaviour may be used to provide that visitor with options or content that relates to their implied preferences; either during a visit or in the future."

Methods used for this kind of tracking include ad tracking, click-through rate, mouse tracking, fingerprinting, cookies/evercookies, session replay scripts and web beacons [1]. Valuable data this may be, but mostly it will not tell us if the user is in trouble right now. In Easy Reading, we need to identify users' problems while viewing a website and, in the ideal case, this information should be derived during a users' first visit since it also might me user's last visit if he or she cannot make any sense of a website's contents. In other words, we need to track a user's cognitive load while viewing a website, which poses a somewhat more complex problem.

To solve this it will probably not be enough to use the usual data that can be derived mainly from a user's mouse movements and clicks. It will be necessary to introduce additional sensors which can expose certain data on a user's overall behaviour during viewing a page.

This document first gives an overview of the State of the Art in user tracking (in the conventional sense as well as more to our point), also including an overview of related EU funded research. Then it shows potential ways of deriving information about a user's cognitive load and in the end discusses the technologies and sensors that are going to be used in the Easy Reading project and why these decisions were taken.

State of the Art in tracking

The following chapters give some examples of relevant state of the art technologies. In addition the CORDIS database has been checked for potentially relevant EU funded research going on.

Google Analytics

Google Analytics is a web and app analytics platform used to track user activity and application performance. It is the most widely used analytics platform and is offered as a freemium product by Google Inc. The product has a strong reporting engine and tracks a number of key dimensions and metrics that are of use when evaluating factors impacting the user experience. Key dimensions and metrics include:

- Operating System and Version
- Browser and Version
- Screen Resolution
- Country / Region / City
- Session duration
- Page View Duration
- Bounce Rate

It also provides an event logging service which is useful for tracking button clicks and user interactions. When implemented as a JS library it is useful in the context of this project since it can store custom metrics such as Page Complexity, Reading Age etc. A correlation or inverse correlation between page complexity and engagement can thus be developed.

FaceReader

FaceReader is a commercial software for interpreting facial expressions to detect emotions. According to Noldus Software [2] it can detect the following conditions:

- Neutral
- Happy (very good recognition)
- Sad
- Angry (good recognition)
- Surprised
- Scared
- Disgusted
- Contempt (experimental stadium)

In addition, it is also capable of estimating the user’s pulse frequency.

A test licence was obtained from Noldus Software and a short test of the features was performed. In our test, the software did not perform as well as claimed by the producers. This, of course, might have been due to the lighting conditions differing from the conditions in the producer’s lab, which at the same time is one of the reasons why this software was not further considered for use in Easy Reading: there are many rules for background and lighting conditions for the software to work properly – these cannot be guaranteed, since Easy Reading is supposed to be used in an every-day context on the users’ home computers with massively changing conditions.

The emotion detection worked well in the test for emotions like happiness and sadness, while it would not work at all for some other emotions (e.g. scared).

Also, the remote heart rate estimation was tested. Apparently, the changing skin colour during heartbeats is used for this. The system needs 10 seconds for calibration before the detection is supposed to work. Unfortunately, this calibration starts over every time the system loses the face for a moment, which happens rather frequently. Once calibrated, the results of the pulse detection are pretty far from the actual values. FaceReader estimated between 95 and 105 bpm, while a measurement with the traditional method (fingers on artery and a stopwatch) resulted in a frequency range between 65 and 70 bpm.

The price for the FaceReader software in a configuration that might have been useful for our purposes is around €10.000,-. There is a cloud version that is cheaper, but it does not give results in real time, which we would need for Easy Reading.

EQ-Radio

EQ-Radio [3] is an experimental system developed by the Networks at MIT group [4], which realises emotion recognition by using wireless radio signals. It uses the reflection of a wireless signal from a user's body to detect individual heartbeats (and their inter-beat-intervals) and breathing cycles. In fact, the detected signal mainly reflects the breathing cycle, which is easier to detect due to the body movement in conjunction with breathing. The heartbeats can then be derived from small dents in the breathing cycle signal [5]. EQ-Radio then feeds these data into a machine learning algorithm and detects human emotions like pleasure, sadness, anger and joy, regardless of the user's facial expression. The system reaches a recognition rate of 87%, which may not be perfect, but pretty impressive for a system that does not affect the user at all.

It was not possible to test EQ-Radio before writing this deliverable since all there is available up until now is one scientific paper. We have, however, contacted the researchers at MIT to find out, if the system might be of use for Easy Reading.

Related research in other EU funded projects

CORDIS (Community Research and Development Information Service), https://cordis.europa.eu/home_en.html, is the European Commission's primary public portal on EU-funded research projects and their results. CORDIS has been the main source in searching for EU-funded research projects on state of the art in user tracking of cognitive load and which may be of interest in the Easy Reading project. Search expressions have been among others "user tracking", "cognitive load", "tracking cognitive load" and "eye-tracking".

Most projects we could find which include tracking of cognitive load in individuals seem to use eye-tracking and measuring parameters like fixations, saccades and pupil diameter. Other measuring methods can be high-tech instruments like EEG, fMRI or low-tech with surveys or tracking behavioural patterns in the interaction with the computer or machine. We haven't found any projects clearly stating that they are measuring heart rate, transpirations and such but we believe some of them do but do not state this in their project abstracts.

When measuring cognitive load with eye-tracking the projects mostly state that they are measuring not only fixations but also saccades and pupil diameter and to do this rather advanced kinds of devices are needed, which are also rather expensive. Cheaper equipment usually measures and records eye-movement and fixation times but not pupil diameter, which is an essential parameter for measurement of cognitive load.

Most projects listed below research something that is not of interest for the Easy Reading project but uses different kinds of user tracking. These methods and how they are processing the collected data might be of interest for us.

For each project, we have stated an "Of interest rating" trying to assess on a scale from 1 (low) to 5 (high) how interesting this project can be for the Easy Reading project. This should only be read as preliminary assessment since we have only read the abstracts published on the Cordis database.

There are six projects which we thought were of high interest (5) and those are:

GTRACK. A project developing a wearable sensor for eye-tracking placed directly on the lens.

SOURCES. Mind-wandering in everyday event comprehension: Memory, attention, and the brain

Digital Iris. An Eye-tracking system that works under controlled real-life environments.

NEOMENTO. Combining VR in CBT with external physiological measures like Eye-tracking and analyses the data to provide a precise therapeutic approach.

WORDINFO. The project is tracking reading time and pupil-size during reading in order to understand language comprehension.

INCLUSIVE. "a new concept of interaction between the user and the machines in which the behavior of the automation system adapts to human operator capabilities"

Projects found in the CORDIS database

EyeTrack - DISRUPTIVE EYE-TRACKING FOR MOBILE EXPERIENCE OPTIMISATION

Coordinator: MATCHIC LAB, France

Years: 2015-2016

Of interest rating: 1

Link: https://cordis.europa.eu/project/rcn/198540_en.html,
http://www.matchic.com/homepage.html

Tracking devices: Eye-tracking

Comments

"The EyeTrack project develops the first eye-tracking system truly adapted to mobile usages and seamlessly combined with a user-testing environment accessible to every digital team."

"Matchic Labs develops a new and accurate Eye-Tracking solution for Mobile Usage and Agile Testing, enabling development teams to easily build tests, collect data, and get results. Fast.
Meant for field-testing with real users, it is built around an innovative eye-tracking system adapted to mobile usages: ultralight hardware, plus Software as a Service environment that analyses visual behaviors of panels of users."

Matchic lab is a company offering solutions for eye-tracking in mobile and web solutions. This project is a development of their mobile solutions. The tool seems to measure fixations and movement but not saccades, pupil diameter and such.

GTRACK - Hybrid quantum dot and graphene wearable sensor for eye-tracking
Coordinator: FUNDACIO INSTITUT DE CIENCIES FOTONIQUES, Spain

Years: 2018-, ongoing project

Of interest rating: 5

Links: https://cordis.europa.eu/project/rcn/216129_en.html

Tracking devices: Eye-tracking

Comments

” The main goal of GTRACK is to demonstrate a semi-transparent eye-tracking system that is disposed in the line of sight of the user, for portable applications. To this end, we will use hybrid Quantum Dot – Graphene photodetectors.”

An eye-tracking device placed directly on the lens.

NeuroPred - Identification of different neuro-cognitive mechanisms of prediction in language comprehension
Coordinator: STICHTING KATHOLIEKE UNIVERSITEIT, Netherlands

Years: 2018-, ongoing project

Of interest rating: 3

Links: https://cordis.europa.eu/project/rcn/215778_en.html

Tracking devices: Eye-tracking

Comments

A research project studying language comprehension using eye-tracking.

TaxInfoProcessing - Information Processing in Tax Compliance Decisions
Coordinator: STICHTING KATHOLIEKE UNIVERSITEIT, Netherlands

Years: 2018-, ongoing project

Of interest rating: 2

Links: https://cordis.europa.eu/project/rcn/215675_en.html

Tracking devices: Eye-tracking, MouselabWeb

Comments

“The present research project applies eye-tracking and MouselabWeb as tools to observe cognitive processes underlying tax compliance decisions.”

SOURCES - Sources of rationality: arousal and the use of rational and heuristic decision strategies
Coordinator: UNIVERSITEIT LEIDEN, Netherlands

Years: 2018-, ongoing project

Of interest rating: 4

Links: https://cordis.europa.eu/project/rcn/215025_en.html

Tracking devices: fMRI, EEG, Eye-tracking

Comments

"The knowledge of the dynamics of attention can be applied to advance our understanding of decision-making and the use of rational and heuristic strategies. The general aim of this project is to explore the neural underpinnings of decision-making. Specifically, this project aims to advance a theoretical model of the impact of arousal on decision strategy use, and to test this model in experiments with the use of various neuroscience methods: fMRI, EEG and eye-tracking. [---] In turn, the applicant will contribute knowledge of value-based decision making, including the knowledge of computational models of decision-making, the impact of stress on cognition and the role of hormones in decision making.

This will allow for a mutual exchange of skills and ideas between the host and the applicant, which should result in novel insights into the mechanisms of decision making."

SOURCES - Mind-wandering in everyday event comprehension: Memory, attention, and the brain
Coordinator: UNIVERSITE DE LIEGE, Belgium

Years: 2018-, ongoing project

Of interest rating: 5

Links: https://cordis.europa.eu/project/rcn/214460_en.html

Tracking devices: Eye-tracking

Comments

"Mind-wandering (MW) is the occurrence of thoughts that are decoupled from immediate perceptual inputs and unrelated to the activity at hand. MW represents a substantial part of our daily thinking time and it has substantial negative effects on reading, memory, and the ability to focus attention. [---] To overcome this barrier, we will leverage new advances in methods to study naturalistic event comprehension in the laboratory. We will adopt a multi-method approach that will combine (i) validated event cognition tasks that involve the viewing of movies of naturalistic everyday activities with (ii) state-of-the-art techniques to measure the behavioral, physiological, and neural correlates of MW. Study 1 will use eye-tracking to determine whether and how the event structure of naturalistic activities affects the perceptual decoupling component of MW."

Machine Vision - Machine Vision in Everyday Life: Playful Interactions with Visual Technologies in Digital Art, Games, Narratives and Social Media
Coordinator: University in Bergen

Years: 2018-, ongoing project

Of interest rating: 3

Links: https://cordis.europa.eu/project/rcn/213474_en.html

Tracking devices: Eye-tracking

Comments

“Smartphones have advanced image manipulation capabilities, social media use image recognition algorithms to sort and filter visual content, and games, narratives and art increasingly represent and use machine vision techniques such as facial recognition algorithms, eye-tracking and virtual reality.

[---]

MACHINE VISION will develop a theory of how everyday machine vision affects the way ordinary people understand themselves and their world through 1) analyses of digital art, games and narratives that use machine vision as theme or interface, and 2) ethnographic studies of users of consumer-grade machine vision apps in social media and personal communication. Three main research questions address 1) new kinds of agency and subjectivity; 2) visual data as malleable; 3) values and biases.

Digital Iris - Bringing the human being into the digital loop
Coordinator: VIEWPOINTSYSTEM GMBH

Years: 2018-, ongoing project

Of interest rating: 5

Links: https://cordis.europa.eu/project/rcn/213615_en.html, https://viewpointsystem.com/de/blogpost/digital-iris-immerese-the-human-being-into-the-digital-loop/

Tracking devices: Eye-tracking, Eye Hyper tracking (EHT), Digit

Comments

“Eye-tracking (ET) technology measures the eye activity to better understand sight, perception, reaction, and emotions, providing a complete bi-directional interaction with the environment. Existing head-worn ET solutions are only able to work in artificial, controlled lab environments.

Viewpointsystem, based on its patented Eye Hyper Tracking (EHT) system, is the only company able to provide a solution that works under uncontrolled real-life environments.

‘Digital Iris’ is the definitive tool to integrate the human being into the digital world. It represents a disruptive leap forward, providing total robustness, reliability and every-day-usability and allowing its use in professional applications whatever the conditions are.”

CybSPEED - Cyber-Physical Systems for PEdagogical Rehabilitation in Special Education
Coordinator: UNIVERSIDAD DEL PAIS VASCO/ EUSKAL HERRIKO UNIBERTSITATEA, Spain

Years: 2017-, ongoing project

Of interest rating: 3

Links: https://cordis.europa.eu/project/rcn/212970_en.html

Tracking devices: Eye-tracking, brain-computer, VR

Comments

"CybSPEED project emphasizes the intrinsic-motivational approach to learning by designing human-robot situations (games, pedagogical cases, artistic performances) and advanced interfaces (brain-computer, eye-gaze tracking and virtual reality) where children and students interact with the novel technology to enhance the underlying self-compensation and complementarity of brain encoding during learning."

NEOMENTO - Redefining Virtual Reality Therapy for Anxiety Disorders
Coordinator: DEUTSCHES ZENTRUM FUR NEURODEGENERATIVE ERKRANKUNGEN EV, Germany

Years: 2017-, ongoing project

Of interest rating: 5

Links: https://cordis.europa.eu/project/rcn/213135_en.html

Tracking devices: Eye-tracking, VR

Comments

"Given that advanced VR technology has become very affordable, a widespread application of VR for the treatment of SAD is now within reach. The proposed project will fuse the applicant's extensive VR expertise with established principles for VR based therapy to create an innovative system for the treatment of SAD. This system will, for the first time, combine interactive 3D environments with external physiological measures (e.g eye-tracking data) and real-time data analyses techniques to provide a precise, flexible and time and cost-efficient therapeutic approach. Established collaborations with clinical partners will allow for continuous testing and refinement of the system, thus ensuring that market readiness can be achieved within the funding period."

The project seems to be using "external physiological measures (e.g eye-tracking data)" for tracking and also analyses it in real time.

ACT - Action research: Improving understanding and methodologies in early development
Coordinator: LANCASTER UNIVERSITY, UK

Years: 2012-2015

Of interest rating: 2

Links: https://cordis.europa.eu/project/rcn/101583_en.html

Tracking devices: Eye-tracking, EEG

Comments

"We will conduct research and training within and between academic and industry partners on the role of attention in action, prospective control, social interactions, and semantics in action. We will improve technologies so that movement analysis is possible with infants. We will also develop an eye-tracking system that links to EEG and we will create tools that are designed specifically for infant EEG data."

WORDINFO - How do words inform? Explaining the role of information theory in language comprehension

Coordinator: STICHTING KATHOLIEKE UNIVERSITEIT, Netherlands

Years: 2013-2016

Of interest rating: 5

Links: https://cordis.europa.eu/project/rcn/107952_en.html

Tracking devices: Eye-tracking

Comments

"Cognition is often said to arise from information processing. Indeed, information theory has been applied to explain aspects of human cognition, such as fluctuations in cognitive load during reading: By computing how much information each word conveys, it can be shown that reading more informative words takes longer, and leads to dilation of the reader's pupils. However, it is as yet unclear how these observed effects of word information come about: What are the underlying mechanisms from which they emerge? The proposed project aims to fill this gap in our understanding of human language, by combining computational modelling and human experimental research.

[---]

Next, in eye-tracking and pupillometry studies, _actual_ reading-time and pupil-size data are collected over the same test sentences as processed by the model."

INCLUSIVE - Smart and adaptive interfaces for INCLUSIVE work environment

Coordinator: UNIVERSITA DEGLI STUDI DI MODENA E REGGIO EMILIA, Italy

Years: 2016-, ongoing project

Of interest rating: 5

Links: https://cordis.europa.eu/project/rcn/205417_en.html

Tracking devices: Don't know

Comments

"The market demands flexible productions lead to complexification of production systems and hence to more articulated Human Machine Interface (HMI). These new features tend to exclude from the working environment elderly people who, even if they have a great experience, feel uncomfortable in the interaction with a complex computerized system. Moreover, complex HMI creates a barrier to young inexperienced or disabled people for an effective management of the production lines.

To tackle these problems, INCLUSIVE aims to develop a new concept of interaction between the user and the machines in which the behaviour of the automation system adapts to human operator capabilities. Hence, INCLUSIVE develops an ecosystem of technological innovations driven by human factors analysis applied to three concrete industrial use cases, carefully chosen to represent a wide range of needs and requests from industry."

NS System - A real-time and continuous brain monitoring system to record and track brain activity and extract biomarkers for neurological conditions
Coordinator: NEUROSTEER LTD, Israel

Years: 2018-, ongoing project

Of interest rating: 2

Links: https://cordis.europa.eu/project/rcn/217149_en.html

Tracking devices: Don't know

Comments

"Neurosteer has developed NS System, a forehead-wearable real-time and continuous brain monitoring system with a dedicated software component that interprets brain signals producing biomarkers for a level of anesthesia, cognitive load, epilepsy and disorders of consciousness."

socSMCs - Socialising Sensori-Motor Contingencies
Coordinator: UNIVERSITAETSKLINIKUM HAMBURG-EPPENDORF, Germany

Years: 2015-, ongoing project

Of interest rating: 3

Links: https://cordis.europa.eu/project/rcn/193801_en.html

Tracking devices: Don't know

Comments

"We will investigate socSMCs in human-human and human-robot social interaction scenarios. The main objectives of the project are to elaborate and investigate the concept of socSMCs in terms of information-theoretic and neurocomputational models, to deploy them in the control of humanoid robots (PR2, REEM-C) for social entrainment with humans, to elucidate the mechanisms for sustaining and exercising socSMCs in the human brain, to study their breakdown in patients with autism spectrum disorders, and to benchmark the socSMCs approach in several demonstrator scenarios."

MOMENTS - Multi-sensory experiences for in-home therapy and entertainment
Coordinator: B & J ADAPTACIONES SL, Spain

Years: 2018-, ongoing project

Of interest rating: 3

Links: https://cordis.europa.eu/project/rcn/217328_en.html

Tracking devices: Don't know

Comments

"MOMENTS aims to bring the benefits of MSEs directly to the homes of end-users. It plans to do so by launching into the market the first lower-scale (and therefore affordable) MSE product. The in-home product will be supported by a unique intelligent system capable of recommending immersive stimulating experiences that adapt to the physical, cognitive and sensory functions of each user (providing more targeted stimulation and easing operation by family members and/or carers). The overall ambition is not only making MSE therapy available 24/7 but also delivering "inclusive entertainment".

Social Digital Lab - Gamified and collaborative digital learning open-source platform with a blockchain-based system to facilitate crowdsourced learning and the implementation of personalized education strategies

Coordinator: FREMEN CORP, France

Years: 2018-2018

Of interest rating: 2

Links: https://cordis.europa.eu/project/rcn/216783_en.html

Tracking devices: Don't know

Comments

"Social Digital Lab provides a complete set of tools and design assistance to create highly engaging, attractive and gamified learning material, personalized to the learner's profile. Its user-friendly interface will facilitate a complete edition of the learning material without requiring programming or graphic & game designing skills. It provides tracking and data visualization tools to check learners' progressions."

Potentially useful Data

Galvanic Skin Response

Galvanic Skin Response (GSR), also known as Electrodermal Activity, describes the electrical activity of the human skin which responds strongly to changes in the mental state. A special type of sweat gland, called eccrine sweat gland that is mostly found on the palms and foot soles, mostly influences GSR. These sweat glands are mostly regulated by the sympathetic branch of the autonomic nervous system and react mainly to psychological and cognitive stimuli [6].

Measurement

This can be used for real-time applications since there are cheap measurement devices available that are also convenient to use. There are two ways to measure GSR. The first method passes a small current through the skin and measures its resistance. Nowadays this is the main method used [6]. Another possibility would be to measure the potential differences without any external currents.

GSR is influenced by the cognitive load as well as the emotional state of the user, which can be problematic if the goal is to assess the cognitive load of the user. However, studies have shown that systems that classify the signal into cognitive load levels can be resistant to emotional changes [6].

HRV (Heart Rate Variability)

Heart Rate Variability (HRV) describes the variation of the time between heartbeats [7]. It is a commonly used measure for the activity of the autonomic nervous system [8]. Studies show that HRV responds quickly to changes in the cognitive state of the user.

Measurement

The most exact method for analyzing Heart Rate Variability is to use an electrocardiogram (ECG) since it provides a clear waveform [8]. However, special hardware is required for this measurement method which incurs additional cost. Conventionally ECG measurement is done by using electrodes that are connected to the chest and limbs. However, nowadays there are small, mobile devices that provide sufficient results [9].

Furthermore, there are studies that show that it is possible to get accurate HRV measures using a normal digital camera that can also capture the cyan and orange color bands [8]. These two colors are necessary since the combination of green, cyan and orange provides the best results. This works by extracting the colors of specific regions of the face and analyzing the data. The advantage of this approach is that these measurements can be done remotely and without additional measurement devices that require skin contact with the user.

An additional source of raw data for HRV calculation is common fitness trackers. These, mostly wrist worn, devices have built in heart rate monitors. Some of these devices allow data extraction in real time thus making it possible to use them as a sensoric device for HRV measurement.

Analysis

There are different ways for analyzing the heart rate Variability. For example, a time-domain method, where the beat-to-beat interval variability is analyzed, can be used [9]. However, this method computes the combined HRV power and does not differentiate between the sympathetic and parasympathetic activity of the autonomic nervous system. Another approach is to compute the power in specific frequency bands using a spectral analysis. There are four main frequency bands that can be analyzed: ultra-low frequency, very low frequency, low frequency and high frequency [8]. The two main components that indicate cognitive load are the low frequency (LF) and the high frequency (HF) components. The high-frequency component reflects mainly the parasympathetic activity, while the-low frequency component is also influenced by sympathetic activity. Studies have shown that the high frequency component and the total HRV power is lower in a scenario that induces high cognitive load than during a normal scenario [10]. Furthermore, it was shown that the LF/HF ratio is significantly higher while under cognitive load.

Eye-tracking

Eye-tracking is already widely used by web designers to test their designs and identify parts where the users have problems with understanding the content [11]. If the hardware is available, this could be used to notice when a user has problems with a specific part in real time and e.g. provide a simplified version. An advantage of eye-tracking is that most laptops already have an integrated camera that could be used for some eye-tracking procedures [12].

Eye Movement Types

There are different eye movements that can be used to detect the cognitive state of the user. These can be split into voluntary movements like fixations and saccades and involuntary movements like blinking and pupil dilation [12].

Fixations refer to a state where the eye is focused and remains still for at least 200-300 milliseconds or longer. The fixations provide information about the area of interest the user is currently looking at, how often the gaze is directed at a certain area and how long the focus remains on a specific area. The number of fixations of the user on any area is called fixation rate.
This can be used to determine the cognitive load induced by a specific area. A long fixation duration and a low fixation rate indicate that an area requires a high amount of cognitive processing [12].

Saccades refer to the gaze movement between two directions. These movements are very fast and typically only last for 30-80 milliseconds. The main parameters that can be analysed are the saccade length and velocity. However, the length and velocity are correlated, which has to be considered for the analysis.
Studies have shown that the saccade velocity and length are related to the cognitive load, where a high velocity and length indicate that the load induced by the task is high. A decrease in these parameters can indicate that the user is tired [12].

Blink Rate is another factor that can be used to determine the current cognitive load of the user. Most of the time blinking is an involuntary eye movement, but it can be voluntary. The latency, rate and velocity can provide information on the current mental state of the user.
A high cognitive load is indicated by a high blink latency and a low blink rate. Furthermore, a decrease in the openness of the eyelids can indicate increasing tiredness [12].

Pupil Dilation is an involuntary pupil movement that can indicate the current cognitive load. The diameter can range between 1.5mm and 8mm. It is important to note that there are other factors, like the brightness of the environment, which can lead to a change of the pupil diameter. However, there are methods that allow calibration of the the eye-tracking device to minimize the influence of the display brightness on the evaluation.
Many studies have shown that an increased pupil dilation indicates a high mental load [12].

Fig. 1 provides an overview of the factors that can indicate cognitive load (originally published by Zagermann, Pfeil and Reiterer in [12]).

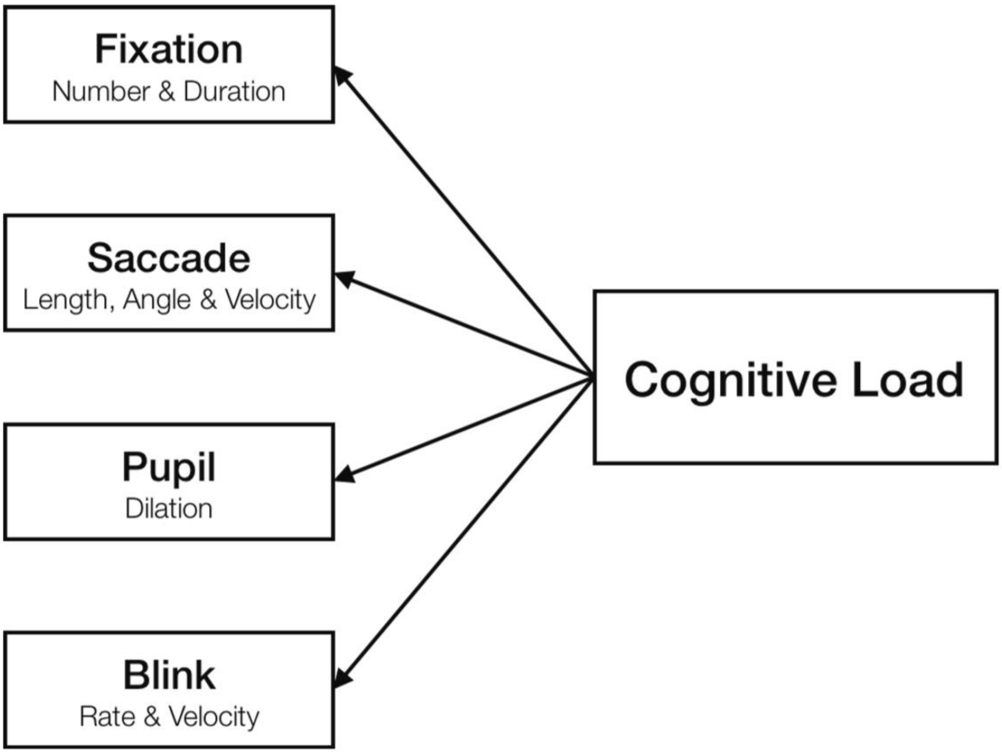

Fig. 1: Eye-based indicators of Cognitive Load [12]

Other influences on eye movements

The Application Design also has a large influence on the different eye movements, e.g. the eye movements made when analyzing an image are different than when reading a text. Social interactions while using the application can also cause different fixations, saccades and blink rates. Different environment variables like humidity, temperature and lighting conditions can also influence the blink rate [12].

Usable Devices

Eye-tracking, especially tracking the direction of the gaze, requires a high capture resolution and framerate[13]. Another important factor is position and movement of the eyes in relation to the camera, which has to be considered for the analysis.

Specialized Eye Tracker Most specialized tools used for eye-tracking illuminate the eye using infrared light. The advantage of this is that the infrared light is reflected more efficiently by the retina than by the cornea. This helps in analyzing the captured images since the pupil is brightly illuminated. The main devices used are either head mounted or remote cameras placed near the display. The advantage of head-mounted displays is that the pupil measurements are very precise. However, head-mounted displays can bother the users when used for a longer time and the precision of remote eye-trackers is enough for most applications [13].

Normal Camera There are projects that implement eye-tracking using only common cameras that are very widespread nowadays, e.g. laptop webcams. This has the advantage of reduced costs. Studies have shown that the precision of these projects can be comparable to specialized devices under specific circumstances [14, 7]. However, the results are highly dependent on environmental factors like lighting conditions, head movements and the resolution of the camera [7].

Mouse Tracking

The great advantage of mouse tracking is that there are no special hardware requirements and also no specific software requirements since it can be directly integrated into web pages using a javascript library [15]. While not as accurate, mouse tracking can provide similar information which can be used to improve the results of the other methods, or substitute them if the hardware requirements are not met.

The speed of mouse movements can also provide information about the mental state of the user. Slow mouse movement, while the user moves the mouse towards an input field or button, can indicate that the user is unsure about that part of the interface [15]. The movement path of the mouse, e.g. if the mouse path is curved or a direct line to a button, also provides information about the cognitive state of the user [16].

However, while there is a correlation between eye and mouse movements of the user, there are large discrepancies between different users. An example for this is that some users move the mouse cursor along the lines while reading a text while other users pause their cursor movement while reading [15]. This limits the resulting information based on user habits.

Another thing to consider is that there are a lot of other input devices that can be used instead of a standard computer mouse. These input devices influence the type, amount and accuracy of the obtained data [16]. The data obtained from a touchpad of a laptop differs from the data of a standard mouse. A reason for this is that the movements when using a touchpad are most of the time more inaccurate. Another example is that the data obtained when using a mouse is very different than when using a touch display. This is getting more important since nowadays touch displays are used in a wide range of devices. Finally one also has to consider a huge range of assistive devices for mouse control, each of which influences the behaviour of the mouse cursor.

Facial Expressions

Facial expressions are often used to detect emotions. Although emotions do not necessarily have to be reflected in the facial expression (e.g. one can feel happy without smiling), they often are and therefore can be used to gather clues on how a person is feeling, which might also have something to do with the cognitive load a person is facing (most people will not be smiling, while trying to solve a tricky problem). Nevertheless, this should not be overrated since many people seem to have the same expression on their face the whole time while sitting in front of their computer.

Selected Tracking Technologies and Sensors

Wristband / Fitness Tracker

Parameters like heart rate variation and galvanic skin response can help to detect someone’s cognitive load (and other forms of arousal). The trouble is, how to extract this kind of data without bothering the user. The usual way to obtain heart rate data is an ECG (electrocardiogram), with electrodes attached to a person’s body. GSR data is usually measured by two electrodes attached to a person’s fingers. So in both the cases, the user would have to get hooked up to several electrodes in order to be able to use the Easy Reading system. While this seems to be perfectly appropriate for a test setting under lab conditions it can hardly be considered realistic that users will want to go through this process every time before browsing the web. In other words: the user must be able to sit down at his or her computer and be able to start surfing right away and there must be no stigmatisation while doing so.

A potential solution to this problem is to find sensors that the user actually wants to wear and, in the ideal case, wears all day, so they do not have to be attached explicitly for web browsing. In the ideal case, it should be a fancy lifestyle product that users might even be proud of wearing, something with a “coolness-factor”.

Now, since fitness trackers have become quite a hype these days and many people wear them 24/7 it seems to be obvious to try using them for the purpose of gathering the needed data. These devices are packed with sensors and some come with an API that allows extraction of certain data.

The first idea was to find a wrist device that measures heart rate variability as well as galvanic skin response and allows the extraction of those data in real time. Sadly it seems that fitness tracking devices that measure GSR are not sold very well. The few companies that used to produce such trackers are either dead or have discontinued production of the devices. The only device still on the market is the E4 wristband by empathica, which is actually not a fitness tracker, but was built for the acquisition and analysis of physiological data for research purposes. Though it is rather unobtrusive, it can hardly be considered a “lifestyle” product and due to the lack of a display cannot even be used as a wristwatch. Also, it comes at the price of about $1.700,-, which raises the problem of affordability. Therefore it was decided to go with a device that does not support GSR, but only HRV, which opens a whole range of possible devices on the market, since HRV seems to be a rising star and is supported by a number of modern fitness trackers.

After having browsed through several options, a good compromise between usefulness and affordability has been found by using the “Vivoactive 3” (see Fig. 2) smartwatch by Garmin [17]. It comes at a price of around €220,- and has a built-in heart rate monitor using 3 LEDs, which makes it more precise than other devices using only two. In addition, Garmin provides an API for developing apps for a number of their watches (using a custom programming language called “Monkey C”, quite similar to Java or C) and a Java-API for communicating those data to an Android device via Bluetooth Low Energy. Another advantage is that the Vivoactive 3 is also available in a version that can be used as an MP3 player, which might make it even more attractive to some users.

Fig. 2: Garmin Vivoactive 3

Eye-tracking

The main problem with Eye-tracking devices is their high price, which somewhat contradicts affordability. If we want to get end users to buy this kind of sensor for their home computer, we need to stay in a reasonable price range and therefore the most professional eye-tracking devices, that come at a price of several thousand Euros, can be ruled out. Sadly only the professional devices support the measurement of pupil dilation, which would have been a useful parameter. Anyway, eye-tracking provides much more useful information, as discussed above, and there are also cheaper devices.

The choice of an eye-tracking sensor was rather easy since the Tobii EyeX is already integrated into the AsTeRICS framework, which saves a lot of development effort. The EyeX-plugin of AsTeRICS can also be used with the newer Tobii 4C [18], which is an eye-tracker made especially for gamers and comes at a price of around €160.-.

Webcam

One of the most common sensors that most users have available anyway is a standard webcam. Together with an emotion detection system, it could be used to get additional information on the user’s condition. An interesting possibility that might be used in Easy Reading is the cloud-based emotion detection service of Microsoft Azure [19]. The usefulness of this will be explored.

Conclusions

Quite a number of measurements can be used for detecting a person's cognitive load, but only those parameters that can be gathered in an unobtrusive and non-stigmatising way. Easy Reading is supposed to be used in everyday life to provide help whenever browsing the web, so after having been set up once it should be usable without any additional effort. For that reason, the sensors used must either be attached to the computer, not the user (e.g. eye-tracker), or they need to be worn all the time by free will and without stigmatising the person. Therefore the sensors that are going to be used in Easy Reading are eye-trackers, webcams and a standard off-the-shelf fitness tracker, which can provide heart rate values to the system.

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