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ANALYSING VISUAL BEHAVIOUR IN ENGINEERING DESIGN BY EYE TRACKING EXPERIMENTS

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ABSTRACT

In the past few years several experiments in cognitive science, human-computer interaction and marketing research impressively showed that eye tracking is a powerful research method to gain deeper insights in human behaviour. However, until now in engineering design research only a small number of eye tracking experiments have been conducted. But even these experiments indicate that eye tracking technology can lead to highly important research results. This paper introduces four different fields, where eye tracking experiments can support engineering design research in order to better understand human behaviour in the context of (1) product representations, (2) engineering design expertise, (3) design creativity and (4) product application. The paper especially focuses on the first aspect by presenting eye tracking experiments, in which the scan path of several test persons analysing a technical drawing is recorded and evaluated in order to identify patterns in their visual behaviour. Based on the results, it finally is discussed how visual behaviour can be purposefully described in design research and how the engineering designer can be effectively supported in design practice.

KEYWORDS

Eye tracking, visual behaviour, engineering design, experimental research, product representation

1. INTRODUCTION

1.1. Motivation

The day-to-day business of engineering designers in industry is characterized by the transfer of customer needs into a functional product design. Most of these designers are very successful in developing highly competitive and differentiating products. If they are asked how they think and act while designing these products, most of them have difficulties to make their way explicit. Many of them even claim that they are not using any kind of methodology and that their success is based on experiences and intuition. They simply know, what to do and how to do it, but they have difficulties to explain their individual approaches. Their knowledge is tacit knowledge – used in tacit processes and tacit methods.

In order to be accepted in engineering practice, design methods and tools have to strongly consider the way engineering designers think and act. On the one hand these methods and tools have to support novice engineering designers in order to support them developing their own successful way to work easier and faster. On the other hand the methods and tools also have to help experienced designers leading them back on a successful way, when they got stuck in a wicked engineering design problem.

The fundament of a design methodology with the aims mentioned above bases on a deep understanding of the ways how experienced designers think and act. At this point eye tracking experiments provide a great opportunity to gain valid research data and thus new insights in the cognition and behaviour of engineering designers.

1.2. Relevance

Visual perception strongly influences the thinking and acting of human beings and eye tracking is the corresponding computer-aided research method to record and analyse this behaviour. Eye tracking systems continuously measure the point of gaze and thus support the identification of a test person's areas of interest within the respective field of vision.

Schon and Wiggins [1] emphasizes that in seeing the designer not only visually registers information, but also constructs its meaning – identifies patterns and gives them meanings beyond themselves: words like recognize, detect, discover and appreciate denote variants of seeing, as do such terms as 'seeing that', 'seeing as' and 'seeing in'.

Knowing where a person is looking while solving engineering design problems can give important insights into individual thinking processes. Eye tracking in engineering design research helps to understand, why individuals divert their attention and how and when they make use of visual information. Eye tracking data will not reveal by itself what a person is thinking, but it can be used in combination with other research methods to understand the thoughts of an engineering designer and to objectify his or her heuristics.

Due to major technological progresses in the areas of computing and microelectronics, eye tracking systems recently made a huge improvement step. Modern systems are small and highly integrated and thus, they can be applied in real working environments without influencing a test person by annoying uncomfortable eye tracking devices. In addition to this, the eye tracking systems now available on the market are highly user-friendly. They support the researcher by automatic calibration, statistical analysis methods and additional raw data visualisation and evaluation software. They allow conducting experiments with significant results. Consequently, modern eye tracking systems are mature to be applied in engineering design research even in large studies.

Today, eye tracking is already well-established in neuroscience, psychology, industrial engineering and human factors, marketing/advertising and computer science. The results within these research fields show the high potential of eye tracking to gain new insights in the thinking and acting processes of human beings.

In the eye tracking experiments conducted by these disciplines (1) similar tasks (e.g. search for locations or search for flows) are assigned, (2) similar segmentations of the test persons (e.g. culture, sex or age) are defined and (3) similar measurement readings (e.g. fixation duration or dwell time) are recorded and evaluated.

In engineering design research the usage of eye tracking is still at its beginning and consequently, the key idea is to transfer successfully applied research approaches from other disciplines to engineering design.

1.3. Structure

The paper starts by giving a short historical review of eye tracking technology introducing the applied measurement techniques and eye tracking systems. In section 3 the fundamental terms of eye tracking analysis are explained and discussed in the context of the basic eye tracking data evaluation approaches.

Section 4 presents four different fields, in which eye tracking experiments can support engineering design research in order to better understand human behaviour in the context of (1) product representations, (2) engineering design expertise, (3) design creativity and (4) product application. The potential of each research field is fortified by the results of eye tracking experiments that are conducted by other disciplines, but characterized by comparable objectives and constraints.

Section 5 describes the setup and the procedure of a set of eye tracking experiments, in which the scan path of several test persons analysing a technical drawing was recorded and evaluated in order to identify patterns in their visual behaviour.

In section 6 the results of these experiments are presented and discussed with a special focus on the purposeful application of scan path patterns and cognitive abilities.

Section 7 concludes and gives an outlook on future research activities.

Figure 1 Video-based eye tracking systems: remote system (left) and glasses (right)

2. TECHNOLOGICAL REVIEW

Eye tracking research has a long history that started more than 250 years ago. The first essays on eye movement surveys are reaching back to the 18th century [2]. Since then different measurement techniques had been developed and integrated in eye tracking systems.

2.1. Measurement techniques

The scleral search coil method is the most direct measurement technique using a sensor in direct physical contact to the eye. It bases on the effect that a coil of wire moved in a magnetic field induces a voltage that can be measured. In order to measure human eye movements, small coils of wire are embedded in a modified contact lens and inserted into the eye after a local anaesthesia [3]. The magnetic field is generated by additional coils that are usually placed on the head. Although the scleral search coil method is the most precise measurement technique, it also is the most intrusive one [4].

Electrooculography (EOG) was the most widely applied technique to measure eye movement during the mid-1970s. [4]. It relies on recordings of the electric potential differences of the skin surrounding the eyes. In order to captured eye movement data several electrodes have to be placed near the eye. Bulling et al. [5] even integrated these electrodes into a wearable EOG goggle. This measurement technique is able to detect eye movements even when the eye is closed (e.g. while sleeping). However, according to Holmqvist et al. [6] EOG systems still exist as a low-cost variety of eye tracking having a high sampling frequency, although the accuracy is poor due to drift.

Video-based measurement became accepted since computers are powerful enough to support real-time eye tracking [2]. Today, this is the most widely applied eye movement measurement technique [7]. The technique bases on the measurement of light reflection triggered by an infrared light source. Eye tracking systems emit light onto the eyes and measures the eyes' corneal reflection relative to the location of the pupil centre. Based on this measurement reading the present point of gaze can be calculated and visualised by a corresponding eye tracking software. The key advantage of video-based measurement is its high user friendliness. Due to the fact that this technique is non-invasive (i.e. there is no physical contact to the test person required) video-based systems are more suitable to support engineering design research, although they do not achieve the same accuracy as the systems using the scleral search coil method.

2.2. Eye tracking systems

Eye tracking systems can be further subdivided into remote systems and head mounted systems (cf. figure 1). A remote system is used to determine the gaze relative to a picture or a video presented on a stationary screen, whereas a head mounted system (e.g. eye tracking glasses) measures the gaze path relative to the 'scene video' showing the test person's field of view, which is simultaneously recorded by an additional camera integrated in the glasses. Due to the static installation, remote eye tracking systems are generally easier to operate, whereas head mounted systems allow the test persons maximum mobility, in particular if the recording computer is small and lightweight [6].

3. EYE MOVEMENT

3.1. Fixations and saccades

Eye movements can be basically categorized into two basic events: fixations and saccades. According to Holmqvist et al. [6] the most reported event in eye tracking in fact does not relate to a movement, but to the state when the eye remains still over a period of time. If the gaze focuses on a local area (typical angle: 0.5°-2.0°) for a certain time (minimum duration: 50-250 ms) this is called a 'fixation'. Fixations indicate that a person gives special attention to the presently gazed scene in order to perceive information from it. Thus, the measurement of fixations (primarily including gaze position and fixation duration) is of particular importance for research applying eye tracking analysis.

The eye movement from a fixation to another is called a 'saccade'. Saccades are very fast, but also accurate eye movements. Human eyes are usually moving with a velocity of 30-100°/s and an acceleration of 4000-8000°/s². During a saccade human beings are almost blind. Nevertheless saccades provide additional insights in the relations of fixations. By measuring the number and the order of saccades, gaze transitions as well as whole scan paths can be recorded and analysed.

3.2. Attention maps and areas of interest (AOI)

Eye tracking systems measure the eye movement and project the calculated gaze onto the record of the test person's field of view, which is also called the 'stimulus'. In eye tracking analysis the stimulus usually is a picture, a sequence of pictures, a movie or the scene video. Thus, eye tracking analysis bases on the combined interpretation of eye movement data and the stimulus data.

A widely-used approach to visualize this combination of data is attention mapping. As described above fixations are indicators for visual attention to certain areas of the stimulus. Thus, in order to map a person's attention, the gaze's dwell time have to be graphically represented for every point of the stimulus. A popular representation form contains highlighting regions of many or long fixations by warm colours and marking regions that are less considered by cold colour. In doing so, the stimulus (e.g. a picture) is overlaid by a 'heat map' representing the areas of high visual attention by flame red hot spots [7]. In addition to heat maps (warm/cold) visual attention can also be represented by luminance maps (light/dark) and contrast maps (sharp/blur). Although attention maps provide a quick and very intuitive representation of eye tracking data, they usually not fulfil the high level of accuracy and unambiguity as required for drawing valid research conclusions.

Nowadays, most scientific eye tracking studies are conducted by application of 'areas of interest' (AOIs). AOIs are relevant areas on the stimulus that are usually defined before starting the experiment. The definition of AOIs is closely connected to the research question and the corresponding research design. There are three basic AOI events [6]:

- the AOI hit, i.e. there is at least one fixation inside of the AOI,
- the AOI dwell, i.e. there are two or more sequenced fixations inside the same AOI for a certain period of time and
- the AOI transition, i.e. there are two or more sequenced fixations across different AOIs in a certain order.

Corresponding to the different AOI events presented above several AOI-based representation forms (e.g. transition matrices or Markov models) supporting the quantitatively analysis of gained eye tracking data. The importance of AOIs in research is fortified by Jacob and Karn [8]. In a comparative study they revealed that the data collected within 24 reviewed eye tracking experiments was analysed regarding the following six metrics: (1) overall number of fixations, (2) overall gaze % (proportion of time) on each AOI, (3) overall fixation duration mean, (4) number of fixations on each AOI, (5) gaze duration mean on each AOI and (6) overall fixation rate (fixations/s).

Attention maps as well as AOI representations are often illustrated in combination with scan path visualizations (cf. figure 3). Scan paths graphically represent saccades by a sequence of curves or vectors that are typically projected onto the scene. Scan path visualizations can provide an excellent overview of one specific record of eye tracking. However, already old-established scan path analyses impressively showed that the scan path for a given stimulus is depending on both the individual experience of a person and the task assigned to this person [9]. Thus, scan path visualizations can be especially valuable in eye tracking analysis focusing on individual visual behaviour.

4. EYE TRACKING ANALYSIS IN ENGINEERING DESIGN

4.1. Analysing product representation

Product representations are explicit descriptions of the product including a selection of its characteristics and properties. In addition to textual representations, in engineering design especially functional and geometrical representations are of particular importance. Here, product models illustrate hierarchical and structural interdependencies of single elements or subsystems. Furthermore sketches, technical drawings and 3D-CAD-models are built up to document and to communicate the product's embodiment [10]. These product representations are characterized by both high information content and high information density. The information contained in the respective product representations has to be perceived and processed primary visually. Thus, the application of eye tracking seems to be most suitable for the analysis of product representation and the identification of correlations to visual behaviour.

In the context of functional and geometrical representations eye tracking analysis is already successfully applied in different other fields of research. Bednarik [11] for example analysed the visual attention strategies of programmers debugging software code that is displayed in multiple representations. Rosengrant et al. [12] applied eye tracking in order to record the gaze path in the evaluation of electrical circuits represented in simple 2D-drawings. The findings of both studies indicate that the duration as well as the order of eye fixations is related to the test person's understanding of the respective representations.

4.2. Analysing engineering design expertise

In the context of engineering design education several studies had been made to understand the differences between how novice and experienced designers approach design tasks. As a central finding Ahmed et al. [13] describe that novice designers tend to use a particular pattern of trial and error whereas experienced designers use particular design strategies. In consequence they suggest that when developing support methods for novice designers, consideration should be given to informing them of such strategies in addition to providing them with knowledge and information. One essential part of these design strategies are visual analytics strategies. The identification of such strategies is a challenging research task and conventional research methods like interviews, document analysis and protocol studies are currently reaching their limits regarding the accurateness and validity of measuring data. At this point eye tracking analysis provides the opportunity to decisively improve the research of experts' strategies and thus allows a more sophisticated support of novice designers in engineering design education.

Promising studies are recently made in medical science. Litchfield et al. [14] applied eye tracking to analyse the identification of pulmonary nodules in chest x-ray inspections in order to gain insights into the search behaviour of novice and experienced observers. Their experiments confirm that novice radiologists benefit from following the gaze path of an expert while simultaneously viewing the same x-ray photograph. The key finding of this study considers that the novices' performance is not simply improved due to a general increase in attention or to the observer's knowledge that an expert was helping them. In fact, the experiments indicate that following task-specific eye movements provides additional information about visual analytics strategies, i.e. by following the gaze of experts the novices' attention is guided towards task-relevant areas more often and for longer periods of time.

4.3. Analysing design creativity

Design creativity research primarily considers the scientific analysis of insight problem solving processes [15]. Insight problems are characterized by the fact that solutions that seem most obvious to naive problem solvers do not work. The problem has to be restructured in some kind in order to solve it. In this case the problem solvers have to overcome an impasse in their reasoning in order to infer the problem's solution [16].

Various research works emphasize the strong relations between design creativity and human cognition. Smith et al. [17], for example, analysed how creative impasses can be overcome by evolved analogies. In this context they describe the 'opportunistic assimilation theory' to be one of the relevant theories that are best supported by scientific evidence. The theory states that insightful ideas are triggered by stimuli that are serendipitously encountered some time after repeated failures have sensitized one to an unsolved problem. As the basic challenge for research Smith et al. [17] addresses the fact that in a person's environment there is such a great number of stimuli that it is very difficult to identify the relevant one. At this point, eye tracking analysis seems to be most suitable to support design creativity research. Studies in the field of visual cognition indicate a measurable correlation of analogical forming and eye movement. Gordon and Moser [18], for instance, recently present results showing a greater gaze fixation density for those objects that are most central to the analogical mapping. They further identified patterns of saccade, which are essential for the cognitive connecting of the initial problem and the visual stimuli.

4.4. Analysing product application

In contrast to the sections above, which focus on the measurement of the designer's eye movement, this section discusses the benefits of analysing the user's gaze during product application. Here, eye tracking analysis can be applied to support engineering design regarding the evaluation of usability and customer acceptance aspects. In fact, an essential part of product validation already considers the observation and survey of customers applying physical prototypes or final products. On one hand the testing of physical prototypes can reveal weaknesses of a product's design that should be necessarily eliminated before the market launch. On the other hand the analysis of products in market can lead to the identification of new customer needs that have to be satisfied by the next product generation. In both cases testing aims at gathering information about the user's perception of the product in its application.

Badni [19] states that one of most common methods used for product evaluation tests is the 'think aloud technique'. He further describes that verbalizing own actions and thoughts during the product application causes additional cognitive efforts that negatively affects the test results. In order to overcome this problem, Badni suggests the application of eye tracking allowing the user to review physical products in a more natural way. Crilly et al. [20] as well emphasize that the visual appearance of a product plays a significant role in determining consumer response. However, the judgment on whether a product is attractive or not, does not only include consideration of whether the product looks good, but also whether it appears functional and says the right things about the owner. Against this background Kukkonen [21] conducted an eye tracking study to analyse the appearance and apparent usability of different mobile phone designs. His findings indicate that eye tracking analysis seems to be especially useful in the evaluation of single design aspects and thus can assist a designer in exactly those design stages focusing on these aspects.

5. EYE TRACKING EXPERIMENTS

In the following the setup and the results of first eye tracking experiments focussing on the aspect of analysing product representation are presented. The experiments were conducted to investigate the visual behaviour of engineering designers trying to understand a mechanical system that is represented in the form of a technical drawing.

5.1. Experimental setup

Due to the fact that a technical drawing is a static representation that is well suitable to be presented on a screen, the experiments were conducted by application of the remote eye tracking system SMI RED 250 (sampling rate: 250 Hz, position accuracy: 0.4°) with a 22'' flat screen (solution: 1680 x 1050 pixels, operating distance: 60-80 cm).

The stimulus shown on the screen during the experiments was a 2D sectional drawing representing an advanced gear drive that is able to transform simple rotatory motion into a combined motion of slow or fast forwards rotation and translation (cf. figure 2). In order to animate the test persons to analyse the technical drawing in detail, the represented design includes one essential functional design error, which the test persons were assigned to find and mark in a limited amount of time.

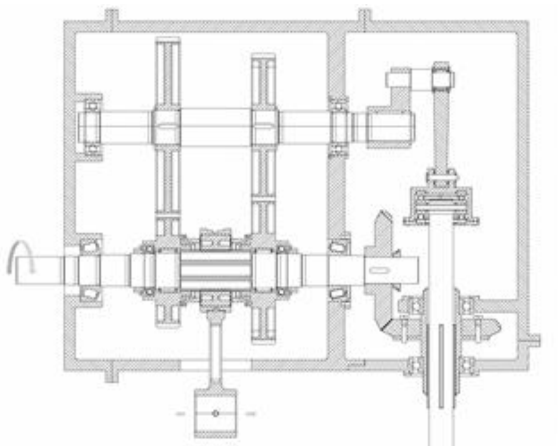

Figure 2 Eye tracking stimulus: 2D sectional drawing of an advanced gear box

The test persons' task was to recognize that the represented gear drive is not able to work, because in operation it would immediately come to a physical collision of the input shaft and the bearing box (down to the right of the drawing).

The experiments were conducted with eight test persons of different expertise levels (undergrad students, postgraduate students and PhD students). All test persons had a mechanical engineering background and were familiar with reading technical drawings.

5.2. Experimental procedure

Each experiment proceeded with the same three sequential stages. The first stage starts with the assignment to analyse and evaluate the represented technical system. In the case the test person recognizes a fundamental error, the corresponding location should be marked by a mouse click. If the test person finds the error, the experiment stops. If the error is not located within a time of seven minutes, the test person is supported by a first hint that informs about the fact that there really is an essential functional design error to be found in the drawing and that this error is not located in the gearshift represented on the left half of the drawing.

At second stage the test person has additional three minutes to locate the error. If the test person again is not able to solve the task, a second hint is given. After providing the advice to think in sequences the third stage of the experiment begins, in which the test person has three more minutes to locate and mark the design error.

6. RESULTS AND DISCUSSION

During the experiments the gaze position of each test person was continuously recorded by the eye tracking system. Following the gained raw data were analysed by application of a corresponding data evaluation software. The results of the experiments indicate that on the one hand there are considerable differences in the visual strategies the test persons applied depending on their individual level of experience [22]. On the other hand also similarities in the test person's visual behaviour were identified considering the usage of (1) basic scan path patterns and (2) specific cognitive abilities.

6.1. Scan path patterns: Skimming and Scrutinizing

The experiments show that while analysing the technical drawing the test persons alternately used two basic scan path patterns: Skimming and scrutinizing (cf. figure 3). These two patterns have been identified in the scan path of all test persons, but the mode and duration of their occurrence varied individually. The scan path pattern *skimming* describes the visual exploration of a larger area of the stimulus. It is characterized by short fixations and long saccades. Skimming is applied, when a person tries to get an overview and relations between single elements are analysed in a higher-level perspective. The scan path pattern *scrutinizing* implies the accurate investigation of a small area of the stimulus. In contrast to skimming scrutinizing is characterized by long fixation and short saccades. Scrutinizing is applied, when a person analyses the details.

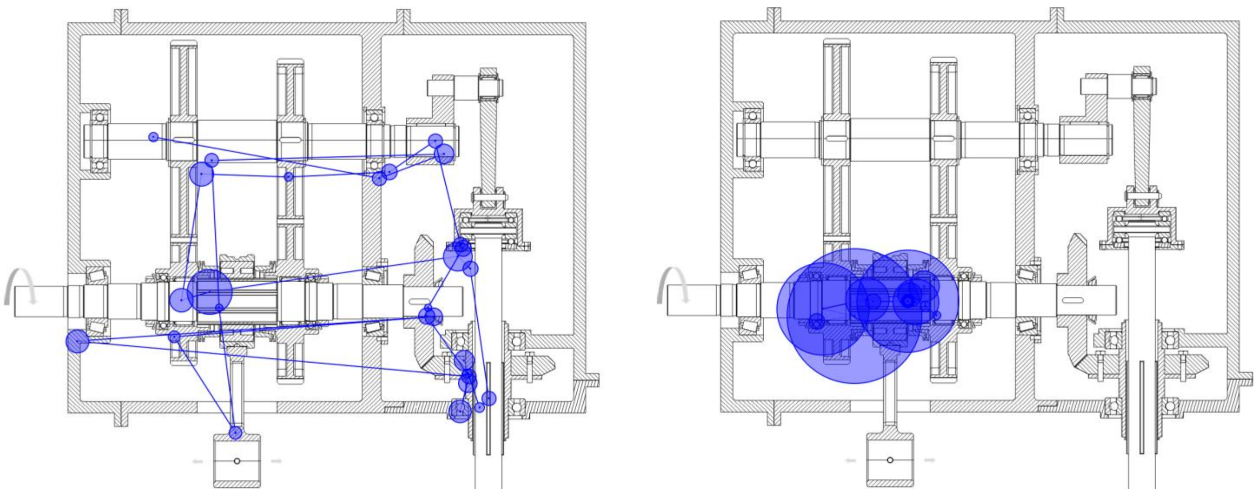

Figure 3 Basic types of visual behaviour: skimming (left) and scrutinizing (right), 7 seconds scan path

The distinction of skimming and scrutinizing seems to be promising to support the description, the differentiation and the comparison of the visual behaviour of engineering designers. In order to guarantee a clear assigning of visual behaviour to either skimming or scrutinizing, first the specific range of characteristic parameters (e.g. fixation duration or event frequency) has to be defined.

6.2. Cognitive abilities: Thinking in sequences

An additional result of the experiments considers the cognitive abilities of engineering designers. This includes not only the ability to spatially imagine the technical system represented by a 2D drawing, but also the ability to bring the system mentally into 3D motion, i.e. to analyse and evaluate the single motion sequences of the system.

The stimulus used in the presented eye tracking experiments allows drawing first conclusions considering the test person's ability to think in sequences. The essential design error causes a collision of component parts, which is not explicitly represented in the drawing and can only be recognized, if the test person imagines a motion sequence that happens after a half turn of the intermediate shaft.

In the experiments seven of eight test persons located the design error before the end of stage three, but four of them did not locate the error until they were directly assigned to think in sequences. This result indicate that most test persons were basically able to imagine the motion of the system, but the technical drawing itself did not activate them to use this cognitive ability. Based on this insight new approaches supporting the designer in thinking in sequences can be developed.

In the experiments all test persons spend a certain amount of time trying to understand the functionality of the gearshift. In order to support this process two arrows indicating the possible positions of the gearshift lever were added to the stimulus (cf. figure 4). The gained eye tracking data show that most test persons repeatedly looked on the arrows in order to imagine and to analyse the single sequences of the gearshift's modes of operation.

Figure 4 exemplary illustrates the gaze path of one test person analysing the gearshift. The figure shows that there are (1) fixations on the gearshift, (2) fixations near the left arrow and (3) saccades between these locations. The visual behaviour– although it can be characterized as a typical scrutinizing activity – reveals that the visual attention of the test person alternates between the supporting arrow and the gearshift subsystem. This indicates that the arrow is used to activate a mental shift of the lever, which leads to the imagination of a motion sequence that is not explicitly represented by the technical drawing.

This example shows that already simple approaches (e.g. additional graphical elements) can impact the visual behaviour of engineering designers and thus can be applied to systematically support the understanding of product representations.

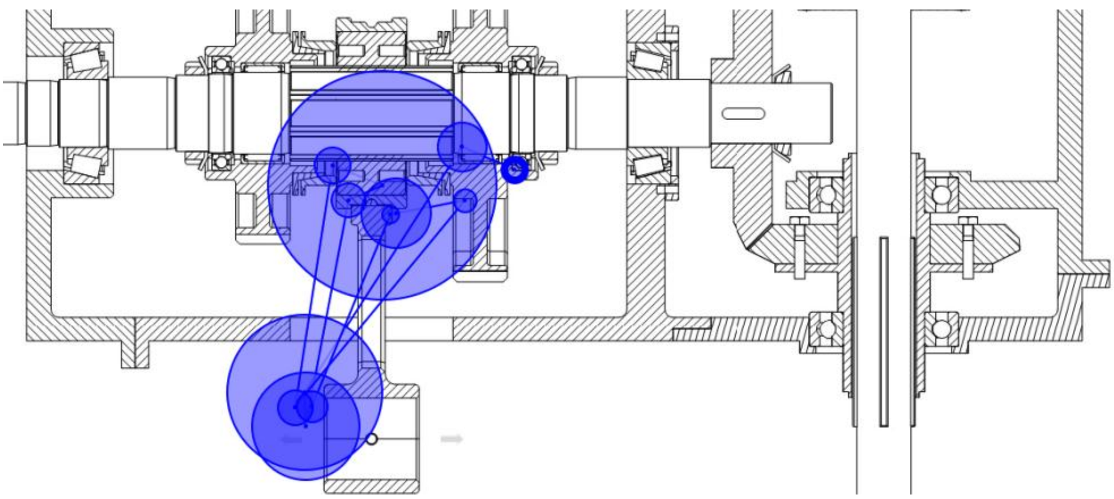

Figure 4 Activation of thinking in sequences by using arrows next to the gearshift lever, 5.6 seconds scan path

7. CONCLUSION AND OUTLOOK

7.1. Conclusion

This paper presents eye tracking as a research method to investigate the visual behaviour of engineering designers and product users. In the last years several experiments in cognitive science, human-computer interaction and marketing research impressively showed that eye tracking is a powerful research method to gain deeper insights in human behaviour. Now, the key idea is to transfer successfully applied eye tracking research approaches from these disciplines to engineering design in order to better understand human behaviour in the context of (1) product representations, (2) design engineering expertise, (3) design creativity and (4) product application.

Eye tracking systems measure the eye movement (fixations and saccades) and project the calculated gaze onto the record of the test person's field of view, which usually is a picture, a sequence of pictures, a movie or the scene video. Modern eye tracking software supports the researcher in the qualitative or quantitate evaluation of the data gained in experiments by event visualisations (e.g. attention mapping) and evaluation systematics (e.g. areas of interest). Due to this, eye tracking provides the opportunity to analyse the behaviour of individuals and still to gain generalizable data providing a valid basis for the development of human-centred design methods and tools.

This paper also presents a set of experiments, in which the scan path of several test persons analysing a technical drawing was recorded and evaluated in order to identify patterns in their visual behaviour. The experiments were conducted with eight test persons from a mechanical engineering background, who were assigned to quickly find and mark an essential functional error in the design of the product represented by the drawing.

The eye tracking experiments revealed similarities in the test person's visual behaviour considering the usage of (1) the two basic scan path patterns *skimming* and *scrutinizing* that are applied depending on whether the test person wants to get an overview or to understand the details and (2) the cognitive ability of *thinking in sequences*, which includes the cognitive transfer from the two-dimensional drawing representation of the technical system to a moving three-dimensional mental representation.

The distinction of skimming and scrutinizing can support design research by providing a basic classification scheme to describe and compare the visual behaviour of different test persons. However, to guarantee a clear assigning, the two scan path patterns first have to be exactly defined.

The results considering the ability of thinking in sequences underline the close relationship of visual behaviour and cognition. Even simple graphical elements can attract visual attention to relevant locations and thus beneficially influence the designer's way of thinking. In order to better understand the dependencies of visual and cognitive processes in engineering design additional experiments have to be conducted.

7.2. Outlook

This paper proposes four potential fields of eye tracking research in engineering design: product representations, design engineering expertise, design creativity and product application.

The experiment presented in this paper is focussing on the first aspect by investigating the visual behaviour of test persons analysing a specific type of product representation. Future experiments will consider other representation forms like e.g. virtual or physical product models. In contrast to the static sectional drawing, virtual or physical product models are dynamic stimuli and thus require more complex evaluation techniques to analyse gained eye tracking data [23].

In the field of design engineering expertise first differences in the visual strategies of novice and experienced engineering designers were identified [22]. These visual strategies have to be further confirmed by additional experiments and probably need to be adapted or extended.

In the context of design creativity eye tracking provides the opportunity to gain additional insights in the interdependencies of internal and external ideation processes. Here, eye tracking glasses will be applied to analyse the eye movement within the iterative process of seeing, imagining and drawing.

Additional experiments in the field of product application will consider the research on how eye tracking analysis can support the identification of customer needs and the evaluation of usability and customer acceptance of a product.

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