ANALYSING VISUAL STRATEGIES OF NOVICE AND EXPERIENCED DESIGNERS BY EYE TRACKING APPLICATION

Quentin LOHMEYER[1], Mirko MEBOLDT[1] and Sven MATTHIESEN[2]
[1]Swiss Federal Institute of Technology ETH Zurich
[2]Karlsruhe Institute of Technology (KIT)

ABSTRACT
In 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 it is described that novice designers tend to use a particular pattern of trial and error whereas experienced designers use particular design strategies. One essential part of these design strategies are visual analysing 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 designer in engineering design education. This paper presents first results of eye tracking experiments that are presently conducted with novice and experienced mechanical engineers to gain additional insights in their visual strategies when analysing design representations (e.g. technical drawings). Based on the results it finally is discussed how identified visual strategies can be trained in design education in order to support the students' understanding of design representations.

Keywords: Eye tracking analysis, visual strategies, design experience, design representation

1 INTRODUCTION

In their day-to-day business engineering designers transfer functional requirements into a corresponding embodiment design. Many of them are very successful in developing highly completive and differentiating products, but if they are asked to explain how they think and act when designing 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 know what to do and how to do it, but they have difficulties to explain their individual approaches. Their knowledge is tacit knowledge.

Design education is about supporting students in the development of exactly this knowledge and these ways of thinking and acting. Against this background Cross [1] explains that design education has well established practices that are assumed to help the progression from a novice learner to an expert performer, but also that there is still rather limited understanding of the differences between novice and expert performance and how to help students move from one to the other. Several studies analyzed the differences between how novice and experienced designers approach design tasks. Ahmed et al. [2], for instance, 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.

This paper presents first results of eye tracking experiments that are presently conducted with novice and experienced mechanical engineering students to gain additional insights in their visual strategies when analysing a gear box design represented in a 2D sectional drawings. Based on a brief introduction in eye tracking technology and application, the experimental setup is described. In the following the results of a first study are presented and analyzed with special focus on the visual searching strategies applied by the novice and experienced test persons.

2 EYE TRACKING BASICS

2.1 Eye tracking technology

Eye tracking technology became increasingly important over the last decade. Due to advancements in the usability of the systems, the reduction of costs and improvements in accuracy and precision, the number of users grew constantly. Today, eye tracking technology is applied in many different domains. Neuroscience, psychology, industrial engineering and human factors, marketing/advertising and computer science are some of the largest application fields of eye tracking technologies [3].
From the technological point of view video-based eye tracking has recently become the dominant technology in use [4]. Video-based eye tracking systems measure the eye movement (relative to a calibration) and project the calculated gaze onto the record of the test person's field of view, which is also called the 'scene'. In eye tracking analysis the scene usually is a picture, a sequence of pictures, a movie or the scene video that is simultaneously recorded by a camera integrated in the eye tracking system. Thus, eye tracking analysis bases on the combined interpretation of eye movement data and the scene data. Video-based systems can be basically subdivided into remote systems and head mounted systems (cf. figure 1). A remote system is able 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) is recording the gaze path relative to the dynamic field of view of the test person.

Figure 1. Eye tracking by a remote system (left) and by head mounted glasses (right)

2.2 Eye tracking in education

In the context of teaching functional and geometrical design representations eye tracking analysis already is successfully applied in different other fields of research. Software engineers for example analyzed the visual attention strategies of programmers debugging software code that is displayed in multiple representations [5]. Researches in electrical engineering applied eye tracking in order to record the gaze path in the evaluation of electrical circuits represented in simple 2D drawings [6]. 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. Promising studies are also made in medical science. Here, researches applied eye tracking to analyze the identification of pulmonary nodules in chest x-ray inspections in order to gain insights into the search behaviour of novice and experienced observers [7]. 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. In this context educational studies (e.g. [8]) recommend for instructional purposes to use the perceptual processes from only one carefully chosen expert instead of averaging across several experts.
The presented studies indicate that eye tracking is most suitable to analyze the differences between visual strategies of novice and experienced engineering designer and that new insights gained by eye tracking analysis allow the development of novel educational concepts.

3 EYE TRACKING ANALYSIS

3.1 Experimental setup

The eye tracking experiment presented in this paper was conducted by application of the remote system SMI RED 250 in combination with a 22'' flat screen (1680 x 1050 pixels). The stimulus, which in this case is the picture shown on the screen during the experiments, was a 2D sectional drawing of a technical system. The sectional drawing selected for the eye tracking experiment represents an advanced gear box that is able to transform simple rotatory motion into a combined motion of forwards or backwards rotation and translation (cf. figure 2). Although the sectional drawing is accurately work out in detail it includes one essential functional design error, which the test persons of this experiment were assigned to find and mark as quick as possible.

The first study was conducted with eight mechanical engineering students of different expertise levels (undergrad students, postgraduate students and PhD students). All students were familiar with the single elements of a gear box as well as their corresponding 2D representation in sectional drawings. Within the experiment each test person was situated in front of the stimuli screen and used a mouse to navigate and mark elements. While searching the sectional drawing for the functional design error the eye tracking system recorded the test persons' gaze position.

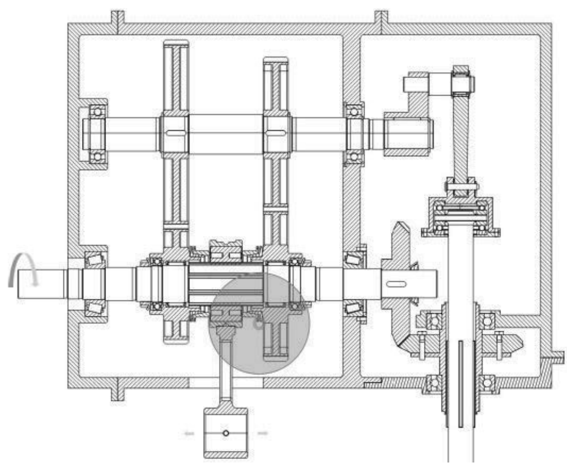

Figure 2. Eye tracking stimulus: 2D sectional drawing including the visualization of a fixation

3.2 Result visualization

Modern eye tracking evaluation software allows different forms of result visualization that graphically emphasizes exactly those locations, where the test person's gaze dwells on for a certain period of time. In eye tracking analysis this is called a fixation. Fixations indicate visual attention to a certain location and the duration of a fixation deliver insights into the particular level of attention intensity to this location. As illustrated in figure 2 a fixation can be visualized by a transparent circle directly on the stimulus, which in this case is the sectional drawing. Its centre illustrates the location the test person is looking at and its diameter represents the duration of the fixation.

During an experiment a test person's attention continuously shifts from one location to another. Here, eye tracking allows recording all fixations including their particular durations. A widely-used approach to visualize this eye tracking results is attention mapping. In order to map a person's attention, the gaze's dwell time have to be graphically represented for every point of the scene. 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. As illustrated on the left side of figure 3 in this result visualization the stimulus is overlaid by a 'heat map' representing the areas of high visual attention by flame red hot spots. Eye tracking also allows the recording of the order of fixations. The results can be visualised by numbers inside the fixation circles or by connecting lines between the fixation circles. The resulting scan path is exemplary illustrated on the right side of figure 3.

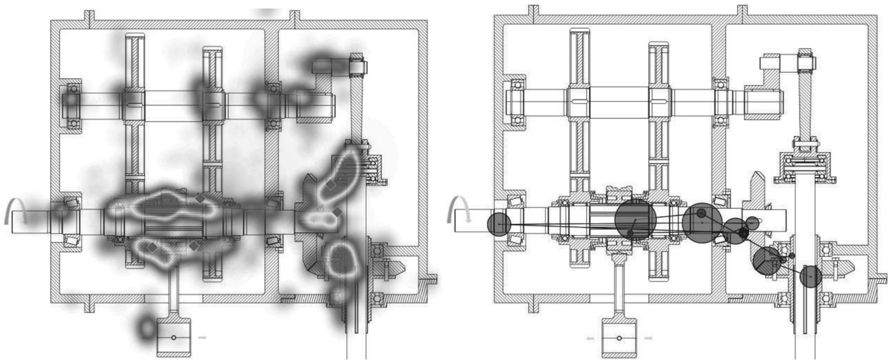

Figure 3. Heat map (left) and scan path (right) on a 2D sectional drawing

4 RESULTS

4.1 Basic findings

The purpose of the study presented in this paper was to collect data about the location and durations of the test person's fixations and to analyze the individual scan paths in order to identify visual strategies that are successfully applied to first understand the sectional drawing and finally to find the hidden design error.

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). This error was chosen, because it causes a non-fulfilment of the overall function. Furthermore the finding of the errors requires an understanding of the function and the ability to imaging states of operation that are not explicitly represented in the sectional drawing.

The experiments indicate that there are considerable differences in the visual acting of the single test persons. A central result is that all experienced test persons found the essential functional design error on their own (some of them even very quickly), while the novice test persons got stuck and asked for help (some of them even several times). Here, the analysis of the collected eye tracking data allowed a detailed insight into the reasons of this outcome.

4.2 Visual strategies

Based on eye tracking analysis, including the evaluation of fixation locations, fixation duration and scan paths, the following visual strategies had been hypothesized:

- *Overview strategy:* Experienced designers at first try to get an overview of the technical system, whereas novice designers tend to directly start with an detailed search without recognizing the system's overall function.
- *Alignment strategy:* Experienced designers align their search with the load flow. They start at the input shaft and check the design of bearings, joints and gears along the way to the output shaft, whereas the attention of novice designers often shifts causeless between different locations.
- *Prioritization strategy:* Experienced designers are able to prioritize their search criteria. They first check the basic functions of all subsystem, whereas novice designers tend to concentrate on one subsystem and additionally check all secondary criteria (e.g. sealing and lubrication).
- *Pattern strategy:* Experienced designers are using scan path pattern to check recurring parts or assembly (e.g. bearing arrangements), whereas novice designers vary in the way they analyze similar components of the system.
- *Internalization strategy:* Experienced designers seem to be able to imaging the dynamic behaviour of moveable parts. Thus, in contrast to novice designers they also check states of the system's operation that are not explicitly represented in the drawing.

The experiments show that experienced designers act more structured and thus are able to search accurate, but also quick. It further indicates that novice designers get stuck because they lose orientation (due to a lack of alignment and/or prioritization) and that they overlook errors, because they are not able to apply visual pattern or imagine motion sequences.

5 CONCLUSION AND OUTLOOK

The ability to successfully apply visual strategies is an important competence of engineering designers. Consequently in design education visual strategies have to be trained by educational concepts based on thinking and acting of experienced design engineers. In order to gain additional insights in the visual behaviour of experienced designers eye tracking seems to be most suitable.

In the experiments presented in this paper the visual acting of novice and experienced designers reading a 2D sectional drawing have been recorded. By eye tracking analysis the fixations and scan paths of the test persons have been evaluated and compared to each other. The experiments indicate that there are considerable differences in the visual acting of the single test persons and that these differences depend on the individual level of experience. Based on a detailed analysis of the experienced persons' test results, five visual strategies were hypothesized: (1) Overview strategy, (2) alignment strategy, (3) prioritization strategy, (4) pattern strategy and (5) internalization strategy. These visual strategies navigate experienced designers through the analysis of sectional drawings and thus allow them an accurate and quick evaluation of the represented design.

The named strategies have to be further confirmed by additional experiments and probably need to be adapted or extended. Future studies will also include eye tracking experiments conducted by application of 'areas of interest' (AOIs). AOIs are relevant areas on the stimulus that are clearly defined before starting the experiment. Due to this fixations and scan paths can be referenced to the AOIs and this allows the gain of more accurate results.

The findings of these research works will provide an excellent basis for new educational approaches allowing students to learn more about visual strategies of experienced engineering designers. Already by simply discussing visual strategies explicitly with the students, their ability to effectively evaluate own designs as well as the designs of others can be trained and thus allows an early improvement of their design performance.

In addition identified visual strategies can be perfectly trained by computer-supported learning concepts. They also can be practically applied in project-based learning concepts. Both ways provide the opportunity to continuously improve the knowledge and the documentation of visual strategies.

Furthermore future experiments will also evaluate the feasibility of eye tracking analysis to assess the level of expertise of an test person regarding a specific task. In this context the binary classification in novice and expert designer seems to be insufficient. Due to this, it will be tested if existing multi-level models of expertise (e.g. [9]) correlates with the results can be gained by eye tracking analysis.

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