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Study project report

Master in Industrial Mechanical Engineering

Mechanics and Automation

<u>CONDUCTION OF PRELIMINARY TESTS TO INVESTIGATE INDUSTRIAL USABILITY OF EYE TRACKING IN MANUFACTURING</u>

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List of abbreviations

HRV	Heart Rate Variability
AR	Augmented Reality
SCR	Skin Conductance Response
FMRI	Functional Magnetic Resonance Imaging
ECG	Electro Cardio Gram
EEG	Electro Encephalo Graphy
GSR	Galvanic Skin Response

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1 Introduction

“In a world of increasing market volatility, shorter product life cycles, higher product complexity, and global supply chains, companies are seeking to become more flexible and responsive to business trends. The Industry 4.0 vision provides recommendations how companies can ease these challenges: The digitalization of the whole product lifecycle will allow companies to use data from production, service, and social media which will lead to faster product improvements. Smart items will bring stronger integration of top floor and shop floor and thus more intelligence and flexibility to production. With these technologies, companies can react faster to demand changes and implement new configurations easier or even re-plan production much faster” (Schmitt, 2013).

As you can see from the citation, industry 4.0 and its ideas are getting more and more important for companies in general as well as for the production and the product development sector. The companies are trying to make a pro-labour environment which enables the worker to operate in a more comfortable way and hence reduce the time and raise the quality of the products. In order to achieve those new goals, new technologies have to be tested and tried to be implemented in the industry.

During the last decennium, the Eye Tracking technology grew rapidly and got popular amongst researchers and practitioners from all kind of disciplines. “Eye tracking technology can be applied to detect which areas of an object an engineer is directing his/her focus and interest while building up a functional understanding. This technology records gaze data of participants, and thus enables access to insights about the thinking processes of engineers” (Matthiesen, Meboldt, Ruckpaul, & Mussgnug, 2013). While Eye Tracking got important in computing domains, it has been always paid less attention in the sector of improving manufacturing or product design processes. Currently the use of Eye Tracking is constricted because of the absence of enough knowledge about the technology within engineering and its feasible advantages through the interpretation of the data.

It is not important to discuss the general importance of biometric measurement in the nowadays industry, which is, in the course of Industry 4.0, very helpful. In this project work, Eye Tracking and its potential in the manufacturing domain is analysed and first approaches on how to apply Eye Tracking in the manufacturing sector is shown and an experiment is done.

2 Literature review

In this chapter a short overview of the literature is given. As research becomes more and more global, it is important to use suitable tools in order to receive meaningful results. For this reason, two databases were used, the internet platform Google Scholar as well as the scientific database Scopus from Elsevier.

Google Scholar provides a simple way to search for scientific literature. You can look across many sources and disciplines: abstracts, books, theses, articles and other web sites.

Scopus, in contrast, is the largest database of peer-reviewed papers in the engineering sector. It includes books, conference proceedings and scientific papers. It provides an overview of the research output in fields of technology, science, medicines and features.

For the enquiry the search terms “Eye Tracking”, Electro Encephalo Graphy “EEG”, “biometric measurement”, “manufacturing” and combined versions of the terms were used as “title”, “abstract” and “keyword” and only papers in English language were considered.

Table 1: Comparison of search results in Google Scholar and Scopus

Search term	Google Scholar [documents]	Scopus [documents]
Eye Tracking	233000	15954
Biometric Measurement	4300	960
Eye Tracking + manufacturing	25200	43
Biometric Measurements + manufacturing	1960	2

Table 1 shows a lot of scientific papers about Eye Tracking and biometric measurement in general. Combined search terms like Eye Tracking and biometric measurement in combination with manufacturing do not lead to much suitable literature. After looking through the results, the most significant papers were selected and will be presented in the following.

First an introduction of general papers on biometric measurement including relevant information in engineering is given. After that, an overview of applications in manufacturing and assembly will be shown.

2.1 Introduction of general papers on biometric measurement including relevant information in engineering

Table 2 shows articles that give general information about biometric measurements. The first article (Ohme, Matukin, & Pacula-Lesniak, 2011) focus on the two methods (i) Electro Encephalo Graphy (EEG) and (ii) Eye Tracking. It demonstrates how consumer neuroscience can contribute to existing marketing knowledge. In our interactive environment brain wave analyses combined with eye movement observations can contribute to useful information. It can for example enrich the understanding of emotional reactions of customers seeing an advertisement. The article also gives information about the history and the theoretical background of Eye Tracking and focuses on the combination of Eye Tracking and EEG. The next Article (Lohmeyer & Meboldt, 2016) is an overview with a specific focus on engineering design of different biometric measurements, such as Heart Rate Variability (HRV), Skin Conductance Response (SCR), Neuroimaging, EEG, Functional Magnetic Resonance Imaging (FMRI) and Remote and Mobile Eye-Tracking. It explains every single method and provides the reader with information about them. It also includes facts about the limitations of biometric measurements in product application and development. Those information are relevant for their potential use in engineering. Article (Kim, Shin, Shin, Kim, & Lee, 2010) presents the multimodal interface which is based on biometric signals. It includes a module which analyses human biometric signal patterns. The interface recognizes user’s emotion and concentration by ECG and EEG patterns. Article (Gwizdka, Hosseini, Cole, & Wang, 2017) is based on an experiment about eye movement and EEG were 24 participants had to read short news stories of varied relevance. The features of eye movement and EEG were computed in the early, middle and final epoch and when important words were read. It shows an increasing divergence in processing relevant vs. irrelevant documents after the initial epoch. Article (Zheng, Dong, & Lu, 2014) is another experiment with 5 participants about a new emotion recognition method which combines EEG and pupillary response, which is provided by the eye tracker. 15 emotional movie clips of positive, neutral and negative categories are watched, and emotion-relevant features are extracted from the EEG and Eye Tracking data. Those are used to build a fusion model in order to improve the performance of emotion recognition.

The above described articles give a good base for understanding the biometric measurement systems, especially EEG and Eye Tracking.

Table 2: General papers on biometric measurement

Article title	Short summary	Keywords (, Findings)
Biometric Measures for interactive advertising **(Ohme, Matukin, & Pacula-Lesniak, 2011)**	The article demonstrates how consumer neuroscience can contribute to existing marketing knowledge, with a focus on two methods: EEG and eye-tracking	EEG, Eye-tracking
The Integration of Quantitative Biometric Measures and Experimental Design Research **(Lohmeyer & Meboldt, 2016)**	Listing of different biometric measurements, also information about limitations of biometric measurements in product application and product development	Biometric Measures
Design and Development of Multimodal Analysis System based on Biometric Signals **(Kim, Shin, Shin, Kim, & Lee, 2010)**	The multimodal interface includes a biometric analysis module that analyses and recognizes human biometric signal patterns. The biometric multimodal interface can recognize a user's emotion and concentration status by Analysing ECG(electrocardiogram) and EEG(electroencephalogram) patterns.	EEG, ECG
Temporal Dynamics of Eye-Tracking and EEG During Reading and Relevance Decisions **(Gwizdka, Hosseini, Cole, & Wang, 2017)**	• Read short texts; eye movement and EEG features were calculated • Participants were asked to find information in short news story texts • 24 (male and female), each participant received $25 • The classification models show increasing divergence in processing relevant vs. irrelevant documents after the initial epoch.	(Page 5) • Artifact Removal • Eye Features • EEG Features • Data Segmentation • Feature Selection • Classification M.

Multimodal emotion recognition using EEG and Eye Tracking data **(Zheng, Dong, & Lu, 2014)**	• New emotion recognition method which combines EEG signals and pupillary response collected from Eye Tracking • 15 emotional film clips of 3 categories (+; 0; -) shown to participants • EEG and Eye Tracking • 5(male and female) between 22-24	• Goals: Build fusion model (to improve the performance of emotion recognition) • Main findings: EEG and pupil diameter are efficient to recognize emotion. Emotion recognition models were built which achieved accuracies of ca 73 % • Parameters: Pupil diameter (changes), feature smoothing (page 3)

2.2 Applications in manufacturing

This section is about the articles which were found in the manufacturing sector. Table 3 gives an overview of applications in manufacturing and assembling. The number of participants in tests range between 6 and 122 and devices used were eye-tracking, EEG and ECG. Article (Renner & Pfeiffer) is about attending guiding techniques in augmented-reality-based assistance systems using Eye Tracking and peripheral vision. In the experiment 20 participants sat in front of a construction area and they had to build a bird house with different guiding techniques. The goal is to evaluate the different augmented-reality-based guiding techniques. A main finding is that using an arrow guidance is the fastest and best rated technique for assembling processes. Article (Hercegfi, et al., 2015) is about a series of experiments which is an explorative research on collaboration behaviour in virtual space. Systems as EEG, ECG and Eye Tracking are introduced and experiments with 122 participants are conducted. Article (Wu, Zhu, Cao, & Li, 2015) is based on an experiment which is about the measurement of influence of information overload on user experience in LED manufacturing systems. In order to gather all the data, Eye Tracking methods and a questionnaire were used. Interface complexity and user background were the important independent variables in the study. The experiment in article (Sausman, Samoylov, Regli, & Hopps, 2012) was conducted with 6 participants and it summarizes a study measuring the eye and body movements of mechanics performing assembly activities in a live manufacturing environment. The knowledge is important for designing a wearable augmented reality system. Article (Guo, Cheng, Cheng, Jiang, & Tang, 2013) focuses on an experiment with 20 participants and is about the intent capturing through multimodal inputs. In summary it can be said, that there is no agreement about how tests with biometric measurement should be carried out and which instruments should be used. Therefore, it is worth it working on that in the framework of this study project.

Table 3: Manufacturing, Assembling – "Industrial operations"

Article	About	Settings	Devices	Nr of participants / Environment/ etc.	Goals	Main findings	Parameters
Attention Guiding Techniques using Peripheral Vision and Eye Tracking for Feedback in Augmented-Reality-based Assistance Systems **(Renner & Pfeiffer)**	Accomplish a bird-house task with different guiding techniques	User sat in front of a construction area where the bird-house was built; bird-house had to be built with AR guidance technique	Eye Tracking and Augmented-Reality (AR)	20 participants (male and female), between 19-27	Evaluate different AR-based guiding techniques	Arrow guidance was the fastest and best rated; baseline condition with images on the display were slower	House was assembled out of seven parts in less than 30 seconds. Measured: • The time to pick a part • The angle and distance to the prior part • The head movement angle • The ratio between eye gaze
Experiences of virtual desktop collaboration experiments **(Hercegfi, et al., 2015)**	The Virtual Desktop series of experiments is an explorative research on collaboration behaviour in virtual space	The VirCA provides a platform where users can build, share, and manipulate 3D content and collaboratively interact with real-time	EEG, ECG, and mobile eye-tracking in immersive Virtual Reality environment	122 (male and female)	Cognitive behaviour, cognitive ergonomics, how to apply EEG, ECG and Eye Tracking in VR environment	See paper (complex)	• Time coded transcriptions • recordings • Eye-tracking of both participants • Pupil size • Heart Rate • EEG

Influence of information overload on operator's user experience of human–machine interface in LED manufacturing systems **(Wu, Zhu, Cao, & Li, 2015)**	This paper reports on an experimental study on human–machine interface in LED manufacturing systems to measure the influence of information overload on user experience.	They designed a multiple-variable experiment study. The two independent variables in this study are interface complexity and user background. The dependent variables are time to first fixation, fixations before and subjective feelings.	LED manufacturing systems, Eye-Tracking methods	38 operators (male and female) ages 18-32	Measure the influence of information overload on user experience	Interface complexity caused a significant difference in time to first fixation and fixations before results revealed differences between high complexity interfaces compared to low complexity interfaces, …	<u>Eye Tracking:</u> • -Time to first fixation • -Fixations before <u>Subjectice metrics:</u> • -Mental workload • -Effort • -Satisfaction • -Pleasure • -Frustration • -Reliable
Effect of Eye and Body Movement on Augmented Reality in the Manufacturing Domain **(Sausman, Samoylov, Regli, & Hopps, 2012)**	This paper summarizes a study measuring the eye and body movements of mechanics performing assembly activities in a live manufacturing environment.	Study performed at a large vehicle assembly facility as mechanics performed their normal activities while wearing the eye-tracking hardware built by the experiment team.	Eye-tracking	• 6 attendees • One data set for each mechanic for each work order (work orders ranged from thirty to ninety minutes)	• Understanding the ranges of physical eye movements • Measuring the movement of mechanics eyes • Computing the percentage of eye movements	Current head mounted display technology would benefit the manufacturing domain	• Understanding the ranges of physical eye movements • Measuring the movement of mechanics eyes • Computing the percentage of eye movements

Intent Capturing through Multimodal Inputs **(Guo, Cheng, Cheng, Jiang, & Tang, 2013)**	This paper investigated multimodal intent delivery and intent inferring in virtual environments. Eye gazing modality is added into virtual assembly system.	user study in which computer students were tasked with various feature matching exercises carried out using the system Interaction3D	• PC • Two cameras • 3D space mouse	20 participants	• Demonstrate the feasibility of eye modality • Explore the way to evaluate and analyze the accuracy of eye modality in Interaction3D	Eye-gazing and hand multimodal cooperation has a great potential to enhance the naturalness and efficiency of human-computer interaction	Two kinds of eye movement states, fixations and saccades are recognized as basic eye movements

2.3 Research question

Looking at the articles in 2.1 and 2.2 compared to the sum of articles found for the key words “Eye Tracking” and “Biometric measurements” in general (see Table 1), shows, that there exist only a few papers about Eye Tracking and biometric measurement in manufacturing. This makes the area interesting for conducting constructive research and leads us to the research question:

Are Eye Tracking and biometric measurement systems applicable in manufacturing and especially in assembly and can they provide information in a more reliable, safer, quicker or smarter way than current practices?

In order to answer those questions preliminary tests in manufacturing were made.

3 Test equipment and assembly case study

In order to conduct the experiments, equipment has been used. In this chapter a general overview of the used equipment and the applied test procedure will be shown.

3.1 Equipment

Tobii Pro Glasses 2

Tobii Pro Glasses 2 is a wearable Eye Tracking object which gives researchers the possibility to capture insights into the human behavior. It records real world environment in real time and shows exactly where a person looks at while the tester moves freely around. It is very interesting to see afterwards how people interact with their environment, what drives their behaviour and what influences decision making. The glasses provide a unique first-person perspective and can also be used as a tool for training and performance enhancement. It consists of a controller software, a recording unit and a head unit, which can be seen in the Figure 1. This Eye Tracking tool can be combined with biometric devices to get an even deeper insight into the human behaviour. With a weight of 45g for the head unit and 312g for the recording unit it is easily portable (TobiiProGlasses, 2018) (TobiiProDescription, 2018).

Figure 1: Tobii Pro Glasses 2

Tobii Pro X2-60 Remote Eye Tracker

The Tobii Pro X2-60 Remote Eye Tracker is a stand-alone eye tracker. It can be used in different setups by attaching it to a laptop or a monitor and it is used for interactions with inputs on screen. The eye tracker can be utilised for research of natural behaviour. Even though the tool is fixed to a laptop or monitor it allows the participant to move during the recording while still providing high accuracy and precision. During the tracking process, the device uses infrared illuminators to get reflection on the corneas of the user's eyes. These patterns, together with others, are saved by sensors. The system uses mathematics to compute the 3D position of the eye balls, which leads to the zone where the participant is looking (gaze point) (Tobii, 2018) (TobiiProX2-60, 2018).

Figure 2: Tobii Pro X2-60 Remote Eye Tracker

TEA CAPTIV T-Sens GSR

The TEA CAPTIV T-Sens GSR is a wireless sensor, which measures the skin conductance (GSR). The GSR correspond to the ability of skin to transmit electricity due to changes in the activity, which implies the secretion of sweat. The changes can be triggered by emotional stimulation. The tool can be easily carried around, for example for free movement researches, since the size and weight of the tool is small (TEA, 2018).

Figure 3: TEA CAPTIV T-Sens GSR

3.2 Test procedure

For the test procedure in the preliminary tests of this study project the number of five participants has been used. All participants were male (random and unintentionally), had an engineering background and were in the age between 24 and 31. Figure 4 shows the workplace and in Figure 5 one of the participants, who wears the Eye Tracking glasses while assembling the cylinder, can be seen.

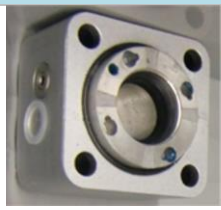
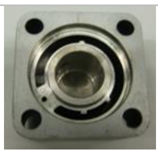
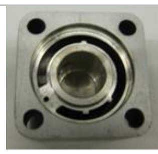
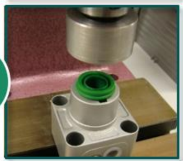
Figure 4: Workplace

Figure 5: Participant while assembling a cylinder

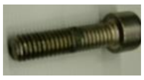
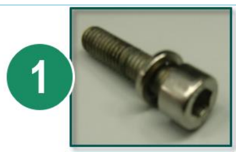
As case study for the use of Eye Tracking devices in assembly, a commercial pneumatic cylinder has been used. The cylinder had to be assembled of several single assembling parts. Each participant had to assemble five cylinders in order to see also efforts of a learning curve afterwards. It was crucial, that the experiment does not last too long since the battery life of the Eye Tracking glasses lasts maximal 40 minutes. During the whole test, the participants wore the Eye Tracking glasses in order to record and later be able to analyse the assembling procedure. It was designated that the participants should wear also the GSR in addition to the Eye Tracking glasses, but it appeared to be not possible because that would hinder the participant to work freely with his hands. As for the Tobii Pro X2-60 Remote Eye Tracker it was not possible to use it either because the participants had to move freely in their working environment and they did not have a fixed position where they looked at all the time. The Eye Tracker is useable only for users who are working on a screen.

In the following the four main subgroups of assembling and the used parts will be explained.

1. Assembly cylinder cover front and back (Operation 1)

	Part 1 – cylinder cover front	Part 2 – cylinder cover back
Ready assembled part		
components	 Housing part front  Seal for piston rod  Damping seal	 Housing part back  Damping seal
Assembly sequence	1  Putting in damping seal 2  Putting on seal for piston rod 3  Putting in rod seal with the help of a hand press	1  Putting in damping seal with the hand

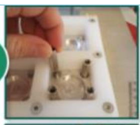
2. Assembly piston mounting (Operation 2)

	piston mounting	
Ready assembled part		
components		Piston
		Retaining screw
		Spring ring
		Piston rod
		O-ring
Assembly sequence		Putting together retaining screw and spring ring
		Placing o-ring on piston rod
		Covering piston over o-ring
		Putting retaining screw with spring ring into opening of the piston
		Torquing down the retaining screw with the power screwdriver

3. Assembly pre-assembly housing (Operation 3)

Pre-assembly housing		
Ready assembled part		
components		Cylinder tube
		Piston seal
		Guide band
		Mounted piston
Assembly sequence		Fixing piston seal to piston
		Fixing guide band to piston
		Sliding the piston in the cylinder tube

4. Assembly final mounting of cylinder (Operation 4)

Final mounting of cylinder		
Ready assembled part		
components		Cylinder cover front
		Tie rod
		Tie rod nut
		Cylinder cover back
		Packaging net
		Piston rod nut
		Mounted piston
Assembly sequence	1 	Putting in the tie rod nuts
	2 	Putting on the cylinder and the cylinder cover front and back
	3 	Fixing the tie rods
	4 	Screwing the cylinder together
	5 	Covering the cylinder with the packaging net
	6 	Putting the ready cylinder in box

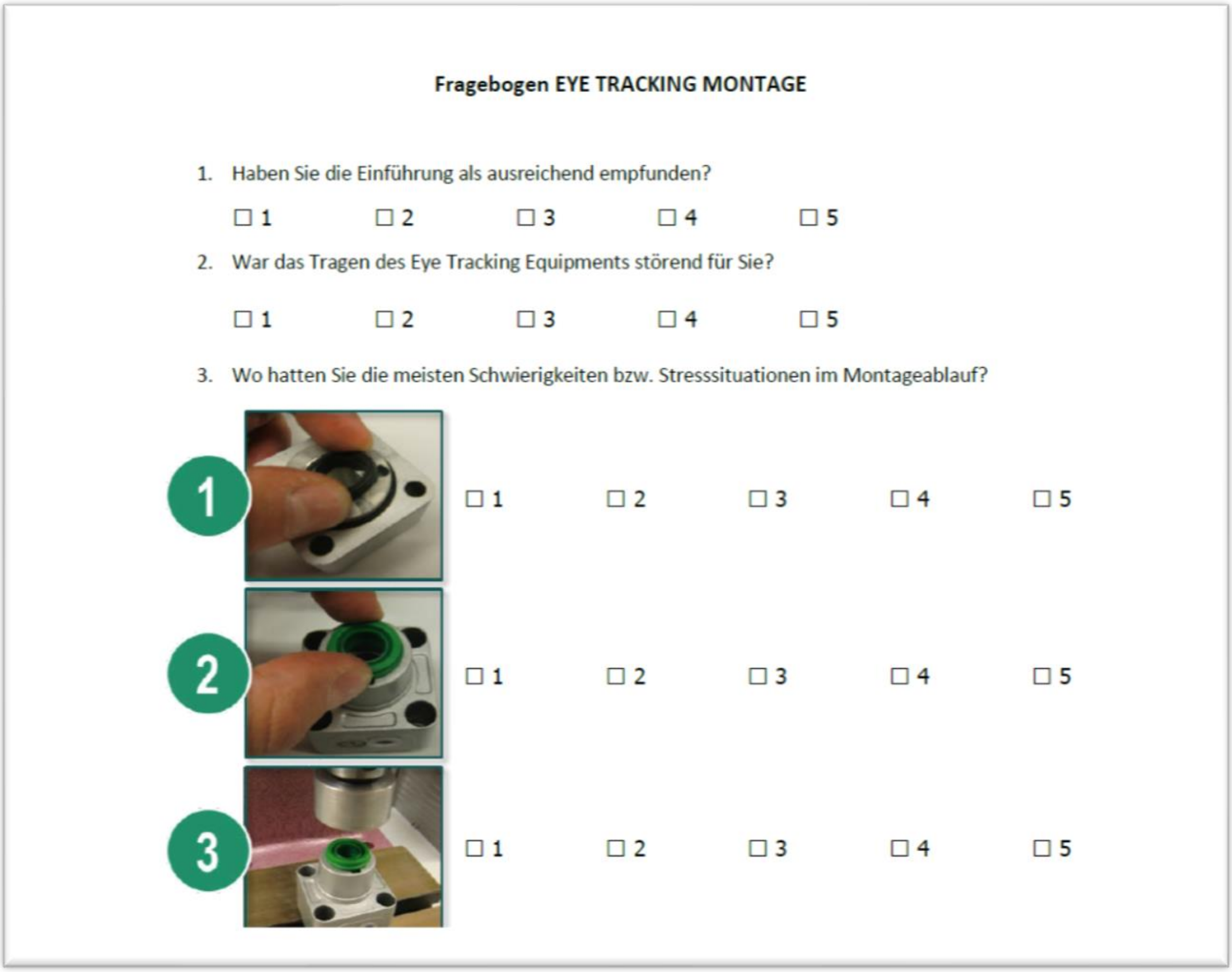
4 Description of test series

All the participants had to assemble five equal cylinders. The four assembling steps are shown in the previous chapter 3. After the conduction of the test series the Eye Tracking data have to be analysed. Therefore, it is important to set time steps to show where an action starts and stops. For defining the steps, eight different categories of operations were established. They are shown in the following table.

Table 4: Established categories with explanations

Category	explanation
Assembling	• putting together two or more components • starts when two pieces are in the right position • stops when next category begins
Break	• each video has five “breaks”, which indicate always the end of the last operation of an cylinder and the time where one cylinder is ready-assembled • time for assembling of one cylinder is always the start of first “operation” till “break”
Handling	• the time when the participant holds a part in the hand and brings it to another place • starts when a piece is in the hand of the participant or when the last of simultaneously searched pieces is out of its box and in the hand of the participant • stops when the next category begins
Information	• searching for information, both in person and in paper • starts when the participant searches for information • stops when next category starts
Operation	• the time after “operation” is always “searching” -time • separates the four different steps of the ready assembled cylinder • first step begins with “operation”, fourth (last) step stops with “break”
Positioning	• starts when the ready part is positioned on its designated place • stops when the next category starts
Searching	• searching with eyes as well as with hands for parts that will be used for the next step • starts when the participant begins to search for pieces in the box • stops when the next category, usually “handling”, starts
Wrong Operation	• starts at the beginning of a wrong operation • stops at the end of a wrong operation

In addition to the assembling of the five cylinder every participant had to fill in a questionnaire, which included questions about the before completed exercise. The participants could answer the questions with a number range from 1 to 5, where 1 indicated total disagreement and 5 total agreement with the question.



Fragebogen EYE TRACKING MONTAGE

1. Haben Sie die Einführung als ausreichend empfunden?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

2. War das Tragen des Eye Tracking Equipments störend für Sie?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3. Wo hatten Sie die meisten Schwierigkeiten bzw. Stresssituationen im Montageablauf?

1 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

2 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Figure 6: Exemplary excerpt of the questionnaire

5 Results, interpretation and discussion

After the completion of the experiments, all the videos were analysed. Therefore, huge human effort was needed. Eight categories were used, which had been explained in the previous chapter. Then the accumulated data were exported by using the Tobii pro software and inserted into an Excel data sheet. A Matlab routine was generated by which the collected Excel data could be sorted automatically. The following table shows a model of how the data were given in the end.

Table 5: Excerpt of the given data after elaboration

1	Tester	Cylinder	Operation(OP)_ID	OP_tot.dur	OP_#fix	OP_fix_tot.dur	OP_fix_max.dur	OP_#sac	OP_sac_tot.dur	OP
2	1	1	1	30399	41	24423	2678	72	4408	
3	1	1	2	38945	49	29935	4537	104	6700	
4	1	1	3	128432	214	92334	2778	399	28639	
5	1	1	4	173112	340	127972	2459	553	36288	
6	1	2	1	28056	43	21754	1779	73	4411	
7	1	2	2	24466	32	18218	2759	66	4737	
8	1	2	3	86383	125	63337	3798	244	16817	
9	1	2	4	89454	170	69733	2838	248	15632	
10	1	3	1	16498	26	12112	1159	46	3046	
11	1	3	2	30470	42	22706	1859	77	5600	
12	1	3	3	70610	112	53115	3638	201	13263	
13	1	3	4	75644	125	60013	4677	194	12446	
14	1	4	1	23623	41	16351	880	78	4954	
15	1	4	2	30195	41	23328	1879	71	4811	
16	1	4	3	59517	84	44988	5757	136	9139	
17	1	4	4	71744	99	55955	4658	183	12740	
18	1	5	1	15694	24	11158	1340	48	3018	
19	1	5	2	29059	40	20709	2299	75	5478	
20	1	5	3	94636	128	69293	3218	224	14595	
21	1	5	4	60182	89	45651	3219	160	11855	
22	2	1	1	28577	49	22105	2139	87	4820	
23	2	1	2	20084	30	15391	3877	51	3164	
24	2	1	3	76083	117	52472	4697	210	15132	
25	2	1	4	72224	124	54953	3358	202	12614	
26	2	2	1	30089	38	25911	2679	61	3099	
27	2	2	2	13688	19	10415	2758	38	2335	
28	2	2	3	56428	94	40208	3458	165	12908	
29	2	2	4	66411	110	50980	3438	177	12292	
30	2	3	1	27993	47	21168	2459	82	4688	
31	2	3	2	29528	37	23213	2638	61	3920	
32	2	3	3	78844	103	65451	5616	172	9355	

The variables that could be extracted are:

1. total duration,
2. fixation,
3. fixation total duration
4. fixation maximal duration
5. saccade
6. saccade total duration
7. saccade maximal duration
8. average pupil diameter
9. standard deviation of a pupil diameter
10. maximal pupil diameter

Those ten parameters are given for each of the eight categories, we identified before.

Total duration

In general, it can be said that there was a shortening in the assembling time visible, which shows a learning curve. In Table 6 the total duration of the assembling of each of the five cylinder and participants is shown and in Figure 7 represented. For each participant the total time, which means the assembling time of the five cylinders together, represents 100 %. It can be seen, that each participant needed more time for assembling the first cylinder compared to the time they needed for the other cylinders. This is because they tried the assembling steps on their own for the first time. Then for the following cylinders, they got used to the steps and they were able to assemble the cylinder in less time. Especially the searching time was reduced during the assembling process. The search for information appeared usually only at the beginning of the assembling process. Also, the positioning time could be reduced because at the beginning every participant had to first learn where to put the parts at.

Table 6: Duration of assembling of each cylinder in percent

Cylinder	1 [%]	2 [%]	3 [%]	4 [%]	5 [%]
Participant 1	31,5	19.4	16.4	15.7	17
Participant 2	21,6	18.3	22.1	18.1	19.9
Participant 3	30,8	16.8	14.3	20.5	17.5
Participant 4	23,8	19.2	19.9	19.6	17.5
Participant 5	31,9	20.7	16.1	16.4	14.9
AVERAGE [%]	27.92	18.88	17.76	18.06	17.36

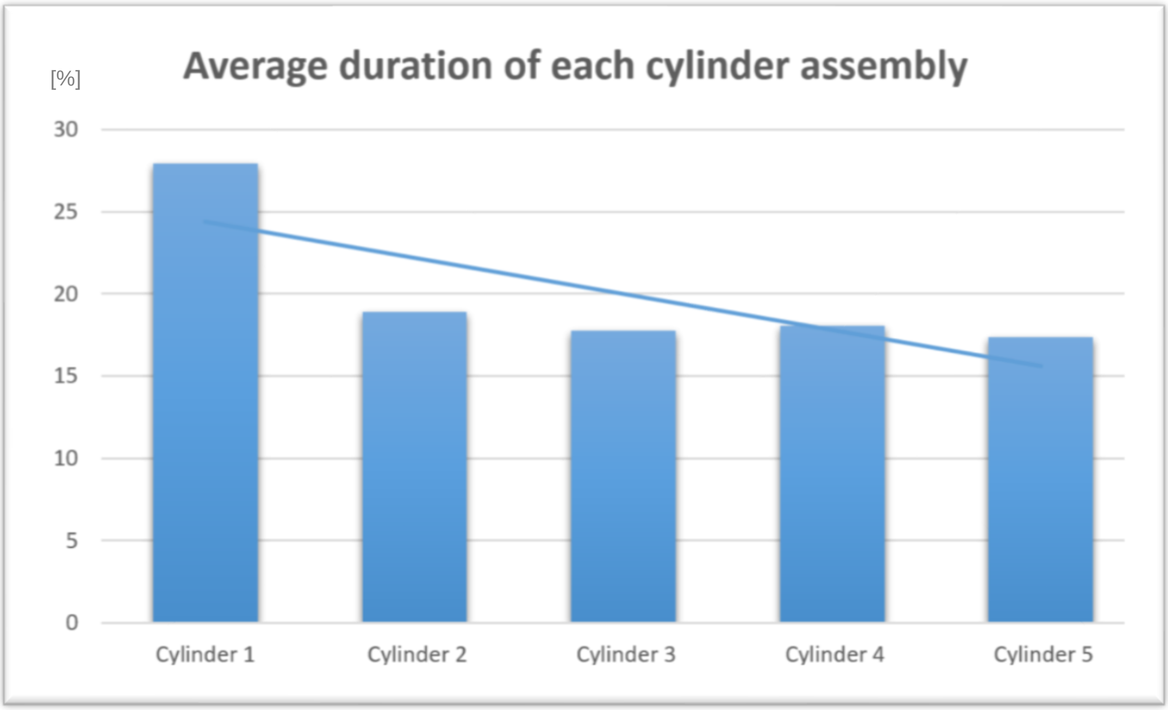


Figure 7: Average duration of each cylinder assembly

Fixation

In Table 7 an excerpt of the fixation data is shown. This was recorded with the Eye Tracking glasses during the assembling of the cylinder where the unit of measurement is milliseconds. It can be seen, that the amount of fixation in operation one and two is lower compared to the operations three and four. Also, the total duration of a fixation of the operation three and four is much higher compared to one and two.

This can be explained with the length of the operations. The piston mounting (operation three) and the final mounting of the cylinder (operation four) is more ambitious and challenging and therefore it is more time needed for completing those assembly steps, hence the number of fixations is higher. This phenomenon can be seen at all participants. It can be proofed with the formula:

$$[Hz\,]_{fix\_OP} = \frac{\#_{fix\_OP}}{t_{fix\_OP}}$$

When the amount of the fixations is divided by the total duration of the fixation the result is between 1 and 2. An excerpt can be seen in Table 8. This shows that there are no irregularities of the fixations.

Table 7: Excerpt of fixation data

1	Tester	Cylinder	Operation(OP)_ID	OP_#fix
2	1	1	1	41
3	1	1	2	49
4	1	1	3	214
5	1	1	4	340
6	1	2	1	43
7	1	2	2	32
8	1	2	3	125
9	1	2	4	170
10	1	3	1	26
11	1	3	2	42
12	1	3	3	112
13	1	3	4	125

Table 8: Excerpt of the division number by time

	A	B	C	D	E	F	G
1	Tester	Cylinder	Operation(OP)_ID	OP_tot.dur	OP_#fix	OP_fix_tot.dur	#/t
2	1	1	1	30399	41	24423	1,34872858
3	1	1	2	38945	49	29935	1,25818462
4	1	1	3	128432	214	92334	1,6662514
5	1	1	4	173112	340	127972	1,9640464
6	1	2	1	28056	43	21754	1,53264899
7	1	2	2	24466	32	18218	1,30793755
8	1	2	3	86383	125	63337	1,44704398
9	1	2	4	89454	170	69733	1,90041809
10	1	3	1	16498	26	12112	1,5759486
11	1	3	2	30470	42	22706	1,37840499
12	1	3	3	70610	112	53115	1,5861776
13	1	3	4	75644	125	60013	1,65247739

It must be considered also the average duration of the fixation in each operation within the five cylinders and in each cylinder assembling, which can be done with the formula:

$$Average\ time = \frac{t_{fix\_OP}}{\#_{fix\_OP}}$$

This can be seen in Table 9. It is recognisable that the average time of the fixations has a tendency towards decreasing with the increasing number of operation. A similar trend is visible also for the cylinders. It is shown in Figure 8.

Table 9: Average duration of fixation in seconds

	Operation 1 (cylinder cover front/back)	Operation 2 (piston mounting)	Operation 3 (pre-assembly housing)	Operation 4 (final mounting of cylinder)	AVERAGE
Cylinder 1 [s]	0.574	0.603	0.498	0.447	0.530
Cylinder 2 [s]	0.748	0.488	0.546	0.457	0.560
Cylinder 3 [s]	0.598	0.560	0.556	0.456	0.543
Cylinder 4 [s]	0.561	0.543	0.547	0.406	0.514
Cylinder 5 [s]	0.508	0.494	0.527	0.427	0.489
AVERAGE [s]	0.598	0.538	0.535	0.438	

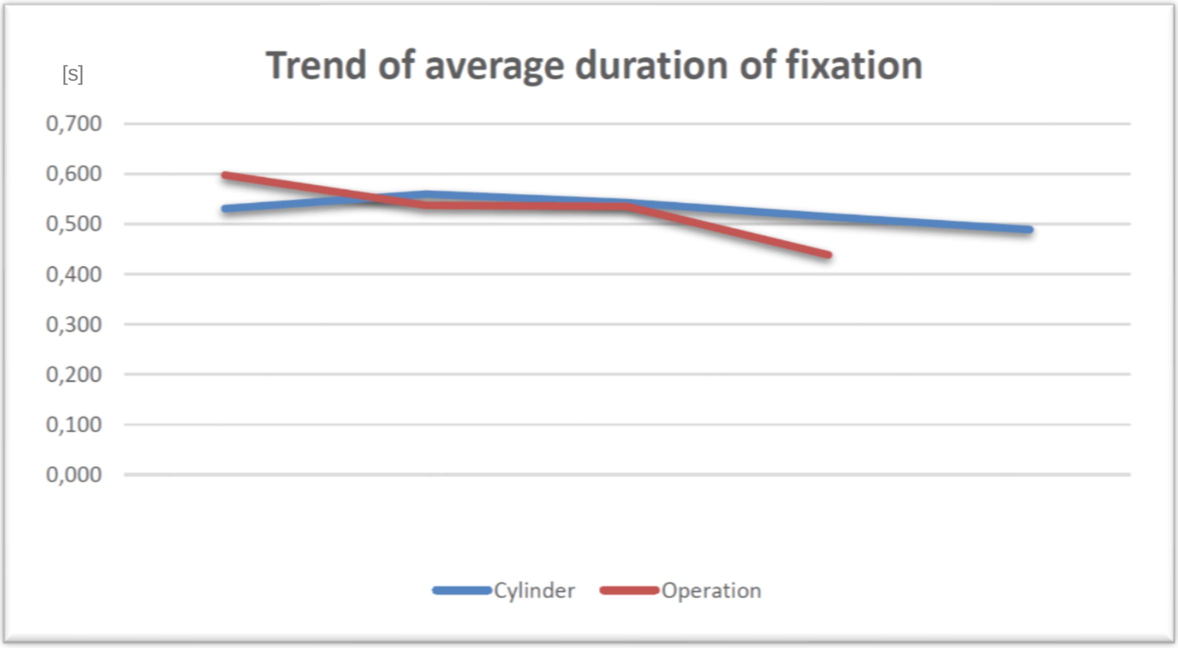


Figure 8: Trend of average duration of fixation

In Table 10 it can be seen, that the average duration of the fixations in the assembling category was the highest. This is explainable because during the assembling process the participants had to look at one point for a longer time. In contrast the average duration of the fixations in the handling, positioning and searching category was lower because the eyes were moving from one point to the other faster.

Table 10: Average duration of fixation in handling, assembling, positioning and searching category

	Handling	Assembling	Positioning	Searching
AVERAGE [s]	0.376	0.677	0.272	0.289

Saccade

"A saccade is a quick, simultaneous movement of both eyes between two or more phases of fixation in the same direction" (Cassin & Solomon, 1990).

It was recorded with the Eye Tracking glasses and the unit of measurement is milliseconds.

The experiment showed, that there is a relationship between the number of fixations and the number of saccades. An extract of it can be seen in Table 11.

Table 11: Extract of the division number of saccades by number of fixations

	A	B	C	D	E	F
1	Tester	Cylinder	Operation(OP)_ID	OP_#fix	OP_#sac	#sac/#OP
2	1	1	1	41	72	1,76
3	1	2	1	43	73	1,70
4	1	3	1	26	46	1,77
5	1	4	1	41	78	1,90
6	1	5	1	24	48	2,00
7	1	1	2	49	104	2,12
8	1	2	2	32	66	2,06
9	1	3	2	42	77	1,83
10	1	4	2	41	71	1,73
11	1	5	2	40	75	1,88
12	1	1	3	214	399	1,86
13	1	2	3	125	244	1,95
14	1	3	3	112	201	1,79
15	1	4	3	84	136	1,62
16	1	5	3	128	224	1,75
17	1	1	4	340	553	1,63
18	1	2	4	170	248	1,46

But it showed also that the average duration of a saccade is much less compared to the average duration of a fixation. In Table 12 can be seen, that there is not much difference between the duration of the saccades in handling, assembling, positioning and searching.

Table 12: Average duration of saccade in handling, assembling, positioning and searching category

	Handling	Assembling	Positioning	Searching
AVERAGE [s]	0.063	0.056	0.072	0.067

Pupil diameter

Very interesting is the measure of the pupil diameter. It was recorded with the Eye Tracking glasses in the unit of millimetres. According to an article of Fanny Jimenez, an author of the daily newspaper “Welt”, the pupil diameter is augmented when the brain is under mental stress and high concentration is demanded. Also, when the brain is under high pressure the pupil diameter raises (Jimenez, 2013). In Table 13 it can be seen, that at the beginning of the cylinder assembling, in operation one, the pupil diameter was the highest and it was decreasing during the other operations. This shows, that each participant had the highest mental stress at the beginning and when they got used to the assembling process the pupil diameter was reduced. Indeed, the highest average pupil diameter of 5.12 mm was measured in the first operation of the first cylinder.

Table 13: Average pupil diameter of each operation

	Operation 1 (cylinder cover front/back)	Operation 2 (piston mounting)	Operation 3 (pre-assembly housing)	Operation 4 (final mounting of cylinder)
AVERAGE [mm]	4.97	4.91	4.87	4.82

Also, the average pupil diameter of each cylinder shows a decreasing trend, which can be seen in Table 14.

Table 14: Average pupil diameter of each cylinder

	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4	Cylinder 5
AVERAGE [mm]	4.94	4.90	4.88	4.87	4.87

By showing those values in Figure 9, the trend towards a decreasing tendency of the average pupil diameter during the experiment in both directions, cylinder and operation, is visible.

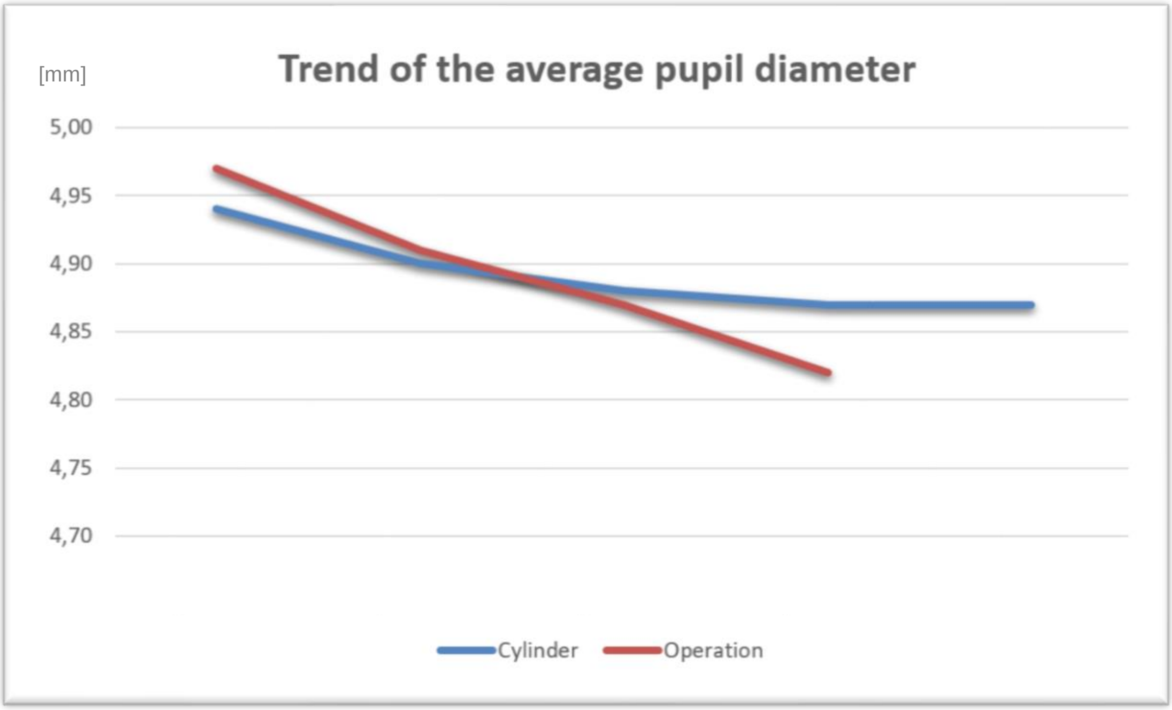


Figure 9: Trend of the average pupil diameter

In Table 15 the average of the maximal pupil diameter of each operation is shown. In the table about the average pupil diameter of each operation it was a decreasing trend visible. According to Table 15 the maximum pupil diameter of each operation is almost the same. This shows that in every operation were moments of high concentration and mental stress, but the amount of those peaks is decreasing.

Table 15: Average of maximal pupil diameter of each operation

	Operation 1 **(cylinder cover front/back)**	**Operation 2** **(piston mounting)**	**Operation 3** **(pre-assembly housing)**	**Operation 4** **Final mounting of cylinder)**
Average [mm]	5.63	5.73	5.76	5.88

Questionnaire

In the Table 16 (see appendix) you can see the summary of the questionnaire of each participant that completed the cylinder assembling. The first question shows with an average of 4.4 out of maximum 5, that the participants were overall satisfied with the introduction and explanation and they understood everything. In the second question it was asked, if the wearing of the Eye Tracking glasses was uncomfortable. The questionnaire showed that two of the participants felt totally uncomfortable with the Eye Tracking glasses. In contrast the other three felt the glasses but didn't consider them as uncomfortable. The average is 2.6 out of maximum 5. The third question dealt with the assembling process and at which step the participant had the most difficulties and stress situations. The answers showed that the most difficulties were at the beginning of the first and at the beginning of the third step. This can be seen in the diagram of Figure 10 on the x-axis at “1S-1”, “3S-1” and “3S-2”.

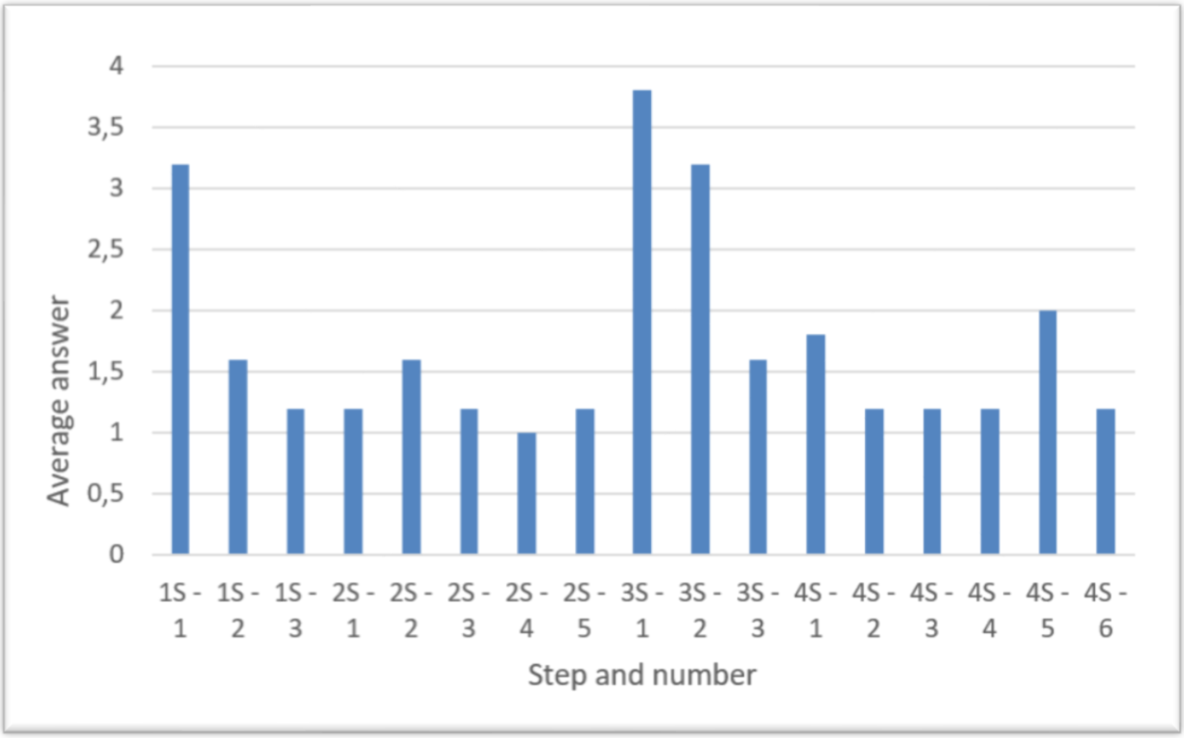


Figure 10: Demonstration of assembling process with average answers on the y-axis and step and number on the x-axis

Additional outcomes

After discussing the data of the Eye Tracking glasses and the questionnaire, there are some additional outcomes that appeared during the conduction of the experiment. First of all, there is the productivity. Through the discussion of the Eye Tracking data and the questionnaire it can be seen at which step the participant had problems, where he was under mental stress and when he was confused. Working on those problems could improve the job satisfaction and increase the productivity. This brings us to the next point, the modification of the workplace. It can be adapted to the worker's needs after the data analysis, which again leads to higher satisfaction. There the separation of the assembling steps could be an idea. If adopted in industry a higher permanent quality might be reached.

The Eye Tracking gives us an even deeper insight than normal videos. This technology compared with the questionnaire can thus help on the application of human factors and ergonomics to adapt the workplace to the requirements of the worker. This can reduce human errors, enhance safety and comfort and increase the productivity.

After discussing the positive aspects of Eye Tracking there are also some disadvantages that should not be left unsaid. The Eye Tracking technology is a mature technology but there are still several things that limit the use. These include the battery duration and the wireless connection of the Eye Tracking glasses with the laptop. Another aspect is the light. “In low-light conditions, the pupil dilates so more light can reach the retina to improve night vision. In bright conditions, the pupil constricts to limit how much light enters the eye […]” (Heiting, 2017). In order to get trustable pupil diameter results, the light at the workplace has to be always the same and should not be too bright. This must be considered during the conduction of an experiment. Also, the object distance should be respected. “In addition to being affected by light, both pupils normally constrict when you focus on a near object. This is called the accommodative pupillary response” (Heiting, 2017). Apart from those problems the amount of data that can be captured is enormous, which include also spontaneous and unintentional people’s behaviors. It means that the analyse and filtration of the recorded videos takes a lot of human work. Before that, the categories must be set, and the videos have to be split. Alone the preparation of one video for the analysis takes about three times as long as the duration of one video. In the end it should not be unsaid that the Eye Tracking system is a foreign body for the participants. This means that the user first has to become used to the glasses in order to achieve real environmental results.

6 Conclusion and outlook

In conclusion it can be said that with this project exploitable outcomes were achieved. Interesting and important information about the status quo of biometric measurement and especially Eye Tracking in the field of manufacturing could be identified and utilised. During the first experiment it was possible to work with the Eye Tracking glasses and test them in real environment and under real conditions. Thereby it was possible to identify and work out the limits, as battery life and the moderate wireless connection of the Eye Tracking glasses and the laptop. After the recording of the participant's eye movements, the analysis of the data starts. Since it was the first time working with the new glasses it was important to first get used to the software and how it is possible to analyse the data properly. Categories for the videos were identified and defined in order to separate each video into measurable parts. In addition, it was possible to get information from the participants about the comfort and handling of the Eye Tracking glasses through the questionnaire.

The citation in the introduction of this report, which was taken from the Digitalist Magazine, talked about reasons, why "Industry 4.0" is relevant and important. The last sentence talked about „these technologies“, with which companies can react faster to demand changes and implement new configurations easier or even re-plan production much faster. One of „these technologies“, is the technology of the Eye Tracking glasses. The research showed that until now nobody really tried to use this technology in order to change the production in a positive and advantageous way. This shows the importance of this project.

As further experiment it would be interesting to make the same experiment with a higher number of participants in order to gain higher reliability and proof the hypotheses that were made. Also, more data could be accumulated and tried to be described. In this work, some assumptions about the importance of the pupil diameter, the fixations, the saccades and the time measures were given already, but a deeper insight is necessary. In addition, this added experiment could let us optimize the handling with the Eye Tracking glasses even better. As a long-term objective, it would be very important to create an algorithm to release the human from the analysis and categorisation of the videos. This could save a significant amount of time and therefore finish this step faster.

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Appendix

Table 16: Questionnaire results

Participant	1	2	3	4	5	Average
Was the introduction enough to understand everything?	5	4	3	5	5	**4.4**
Was the wearing of the Eye Tracking glasses uncomfortable?	3	4	1	4	1	**2.6**
Where in the assembling process did you have the most difficulties/ stress situations?	**1**	**2**	**3**	**4**	**5**	**Average**
1	4	2	3	5	2	**3.2**
2	1	1	2	2	2	**1.6**
3	1	1	2	1	1	**1.2**
1	1	1	2	1	1	**1.2**
2	2	1	2	1	2	**1.6**
3	1	2	1	1	1	**1.2**
4	1	1	1	1	1	**1**
5	1	1	2	1	1	**1.2**
1	3	5	4	4	3	**3.8**
2	4	3	3	4	2	**3.2**
3	1	1	3	1	2	**1.6**
1	2	2	3	1	1	**1.8**
2	1	1	2	1	1	**1.2**

3	2	1	1	1	1	**1.2**
4	1	1	2	1	1	**1.2**
5	2	1	4	2	1	**2**
6	1	1	2	1	1	**1.2**