Efficiency Measurement of IT Support for Information Retrieval at Manual Workplaces

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***Abstract*—The increasing demand to customize vehicles and thus the higher product variety affects the workplaces at the automobile industry. The work tasks become more complex due to an increasing information density and modern production technologies, i.e. robots, linked production facilities and the progress towards the digitalization of production steps. Assistive information systems, that provide relevant information to the worker, have been widely researched, but there is little research on evaluating working stations beforehand regarding their potential of implementing assistive systems. Within this paper, we propose a modified application of a standard evaluation method for comparing different representatives of assistive systems, i.e. paper instructions, IT glasses and hand-held devices. Based on a user study at a manual assembly workplace, we compare these assistive systems. Using the Methods-Time Measurement method for comparison, our results reveal that the IT glass and the tablet, as the representatives for IT-supported systems, lead to significant faster task completions and significant differences in the information processes compared to the paper-based instructions. Additional questionnaires concerning the cognitive load and the assessment of the assistive systems regarding the ease of use, level of satisfaction and performance, support the previous findings.**

Keywords—Methods-Time Measurement (MTM); IT glasses; Hand-held Devices; Assistive Systems; Manufacturing; Information Processes; Evaluation Methods; NASA-TLX;

I. INTRODUCTION

Research in the field of assistive systems and mixed reality applications in the field of manufacturing has proposed a large number of visions, prototypes and systems, which have been evaluated in production environments. The production methods change rapidly, automation processes become more important and the information density increases due to the highly customized products. The worker faces a high density of information of each individual production process and has to compete with the processing times of robots and machines to fulfill the task within a fixed cycle time. In literature, a large number of assistive systems, like IT glasses and hand-held devices, has been tested at manual assembly tasks and evaluated based on the key performance indicator (KPIs) such as task completion times, number of errors and questionnaires, expressing the individual impressions of the subjects [1,2,3,4,5]. The review of related work showed that a majority of studies has been evaluated based on the mentioned KPIs. Research also focused on the establishment of an alternative motion analysis in order to create an objective quantifiable evaluation method for manual assembly tasks [6,7]. However, the present motion analyses are either more product-specific or predominantly focused on the emerging movements without a specific consideration of the information processes.

The present paper pursues an objective validation procedure for IT-supported assistive systems, based on the established Methods-Time Measurement (MTM) and the determination of relevant information processes. The tasks performances are divided into phases of mechanical work and information processes. The phases are further analyzed in its basic motions. Based on the dimensions of the information processes, the need for IT-support can be determined and the usability of different IT-devices could be compared. The taxonomy is tested in a laboratory study.

II. RELATED WORK

In the recent decade, assistive systems and IT-support at manual workplaces has been the topic of many research studies. The first application of mixed reality technologies using an IT glass was presented by Caudell et al. [8]. The study was inspired by a manual drilling task at the aircraft manufacturing. The application of the IT glass supported the worker by indicating the drilling positions and distances. Zheng et al. [9] presented a comparison of the application of a paper instruction, IT glasses and a tablet for a car maintenance task. Among others, Büttner et al. [10] and Fite-Georgel [11] represent an overview about the progresses in research on Mixed Reality-Technologies and concepts in terms of assisting human user in different production areas, i.e. manufacturing, logistics, training and others. The majority of the approaches have in common that paper instructions, i.e. printed manuals, glasses, projections and/or hand-held devices were compared based on the key performance indicators, i.e. task completion times, number of errors and questionnaires [3,10, 11,12,13,14,15].

One of the first models of motion analysis was launched by Card et al. [7,16] in the context of evaluating the performance times. The model focusses on the time an expert user needs to perform a given task on a given computer system. Related to the counting of keystrokes, the model has

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been named Keystroke-Level-Model (KLM). Besides measuring the task completion times, the model is focused on the product at hand and does not include the information processes. Further research in this field is presented by Funk et al. [6] with the General Assembly Task Model (GATM), which differs between task-dependent and task-independent motions. Information processes, respective related cognitive motions, are not turned out clearly; they are seen as already included in one process component.

The Methods-Time Measurement (MTM), one of several systems of predetermined times, presents a prominent and widely used motion analysis of manual workplaces. Launched in 1948 by Maynard and Stegemerten [17], the MTM represents a procedure, which analyzes each manual operation into its basic motions and provides a time unit to make the motions quantifiable. The time unit is named Time-Measurement-Unit (TMU) and asses the sum of the process components with $1TMU/10^5$ hours. Even information processes can be described in its basic motions [18,19], which is why we established our concept based on this method.

III. CONCEPT

The presented procedure pursues the identification of the potential for the support of manual workplaces by IT-systems. If this potential is present, the evaluation method serves as decision basis for the determination of the most suitable IT-system. The procedure works as follows: First, the work processes are divided into phases of "mechanical work" and "information processes". The phases are further analyzed using the standardized MTM method to retrieve time values for further calculations. Unlike in a regular MTM, the information phase is measured separately. The results of both types of phases are compared and based on the calculated times of the information phases, a decision can be made, if an IT-support at the regarded workplaces is feasible.

The basic motions of the MTM method for describing manual operations, i.e. reach, grasp, move, position, release, and so on, can be similarly transferred to the phases of the information processes. During the information procurement, reception and transfer, the basic motions emerge as well, which can be analyzed and compared based on the deposited time units in TMU. Even the application of innovative IT-systems and interrelated "novel" operations, i.e. click, touch, scroll, zoom, swipe, and so on, can be quantified with the MTM-standardized basic motions. The type of the IT-system has to be included into the analysis, i.e. certain manual operations just appear while using a particular IT-system. For example, when using the Microsoft HoloLens, a "click" needs to be analyzed for selecting a focused point on the holographic display. In the case of a tablet or comparable, this basic motions does not exist, respective the touch is used to select a certain point on the display surface. In table 1, three operations of IT-systems are described exemplary with the MTM method.

TABLE I. BASIC MOTIONS REGARDING IT-SYSTEMS

Manual Operations			
Basic motion	***MTM Codes***	***Describing MTM basic motions***	***Exemplary IT-system***
Touch	M20A G5 RL2	Bring (M) the hand, respective the finger, which is considered as the tool, over 20cm to the touching point until stop (A). Contact the surface (G5) and release, i.e. give up the contact (RL2).	Tablets, smartphones, smart watches, IT glasses
Click	M20C EF M6C EF M6C	Bring (M) the finger, considered as the tool, to a particular point (C) over 20cm. Check, if the systems reacts (EF). Otherwise, the finger has to be relocated until the system recognizes it. Move the finger over 5cm forwards (M), in this example to a specific point. Check again the system reaction (EF) and move the finger back again (M).	Microsoft HoloLens
Swipe (i.e. page)	M20A G5 M8A RL2	Bring (M) the finger to the touching point over 20cm until stop (A). Contact the surface (G5). Bring (M) the finger over 8cm in one direction. Give up the contact (RL).	Tablets, smartphones, smart watches, IT glasses

By analyzing each emerging operation into its basic motions, i.e. a touch consists of the motions bring, grasp/ contact and release, the IT-related operations can be determined in detail. Following the MTM conditions and terms of analysis, the procedure determines the requirements for an IT-support and thus is an efficient decision base for selecting suitable devices meeting these requirements.

IV. USER STUDY

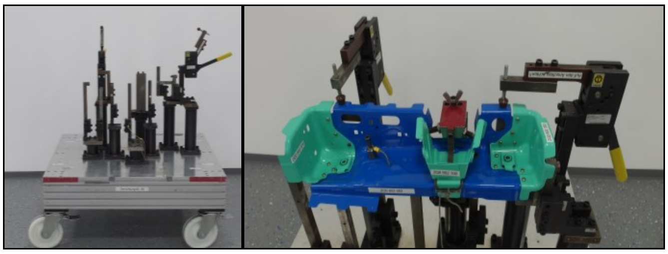
In this paper, we show that the information processes, assessed with the MTM method, represent an effective decision basis for the need of an IT-support. Within a user study, we compared different tools for providing information: paper instructions and representatives of the groups of IT glasses and hand-held devices.

A. Design

The laboratory study was designed as a repeated measure experiment with one independent variable, i.e. the assistive systems, which were used to provide the work instructions. The dependent variables include the relevant information processes, assessed in the MTM format, the task completion times, the perceived cognitive load assessed with the NASA-TLX questionnaire [20,21] as well as the assessment questionnaire for assistive systems. To prevent a learning effect, the usage of the IT systems was permuted over the complete group of participants. The paper instruction was deployed by every participant.

B. Task Description

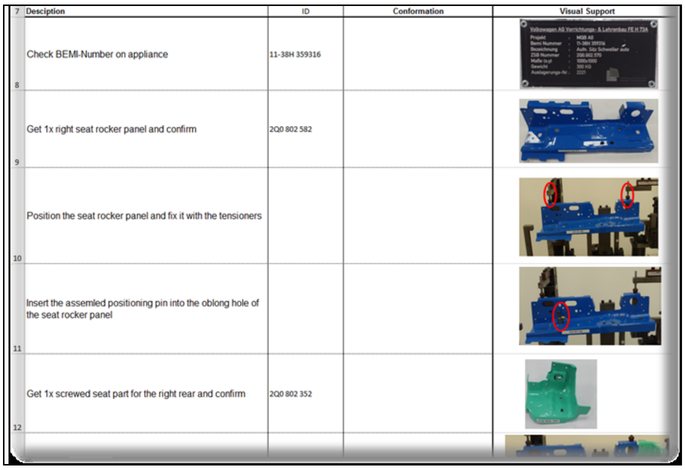
We set up a laboratory study inspired by a manual assembly task of the car body construction of a German automobile manufacturer. The task includes the fitting and fixation of sheet metal parts on special appliance (see Fig. 1 (a)) as well as the screwing to keep the parts together (see Fig. 1 (b)).



(a) (b)

Fig. 1. (a) Special Appliace; (b) Fnished fixed sheet metal parts on the appliance *(Volkswagen AG)*

The conventional task instructions are based on paper work instructions, see Figure 2 for an exemplary excerpt. For the study, we digitalized the paper work instruction and set it into a presentation status for displaying it on the Google Glass and the iPad. An excerpt of some slides is shown in Figure 3.



7	Desciption	ID	Conformation	Visual Support
8	Check BEMI-Number on appliance	11-38H 359316		
9	Get 1x right seat rocker panel and confirm	2Q0 802 582		
10	Position the seat rocker panel and fix it with the tensioners			
11	Insert the assemled positioning pin into the oblong hole of the seat rocker panel			
12	Get 1x screwed seat part for the right rear and confirm	2Q0 802 352		

Fig. 2. Extract of the paper work instruction.

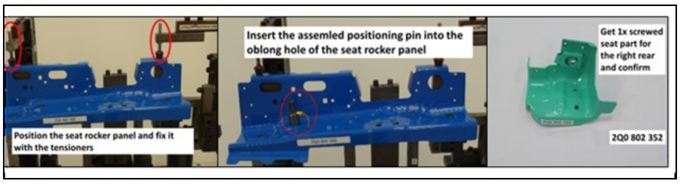


Fig. 3. Excerpt of some slides presented in the work instruction for the IT-systems.

C. *Participants*

Forty participants, twenty female and twenty male, were invited to the experiment via an internal pool of test persons of the cooperating automobile manufacturer. The subjects were aged between 25 to 55 years. The participants were not familiar with the specific work tasks.

D. *Procedure*

Each participant received an instruction of the appliance, the work task and the assigned IT-system. To make the subject familiar with the appliance, we used a different version as the one provided in the study. If the IT glass was allocated, it was first adjusted to the participant. Further, the specific operations of the allocated IT-system was explained. After signing the consent form and secrecy agreement, the participant started the experiment. The same work task was performed twice with different forms of work instructions, i.e. the paper instruction and one of the IT-systems. For the subsequent motion analysis, the determination of the information processes and the measurement of the task completion times, the user study was recorded using three cameras. The recording started with the grabbing of the particular assistive system to read the first instruction sentence. The order of the different work instructions was exchanged for the overall group of test persons, i.e. the half of the group started with the digitalized work instructions, the other with the paper work instruction in order to compensate the learning effect over the entire test data. The study design includes a within-subject design. In total, we received data from forty trials using the paper-based instruction, twenty trials applying the Google Glass and twenty trials performed with the iPad. After each condition, the participant was asked to complete a NASA-TLX questionnaire. After finishing both trials, the participant also completed the assessment of the assistive system and the demographic information form. The overall study per participant took approximately 45 minutes. The diverse data were collected and analyzed in SPSS using non-parametric tests. In Figure 4, the test environment is shown.

Fig. 4. Overall setup of the user study.

V. EVALUATION AND RESULTS

A. *Motion analysis using MTM*

During the motion analysis, the recorded performances are analyzed with the classical coding and time values of the MTM to receive objective results. Further the recorded performances were divided into the phases of "mechanical work" and "information processes". Afterwards, the achieved results were analyzed using SPSS regarding significant differences in the phases of information processes of applying paper work instruction or IT-systems. The testing includes the Mann-Whitney-U-Test for two different groups, e.g. the comparison of the paper-based and the IT-supported work instructions. Considering three groups, e.g. the comparison of the paper work instruction, the Google Glass and the iPad, the Kruskal-Wallis-Test was applied. The phases of the mechanical work were not taken into account in the further steps due to the similarity of the work processes and times.

Considering the information processes, the paper work instruction (M=140.85 TMU, SD=32.858 TMU) shows a significant higher amount of information processing times compared to the IT-supported work instructions (M=72.96 TMU, SD=21.40 TMU), i.e. the applied iPad (M=69.97 TMU, SD=26,.29 TMU) or Google Glass (M=77.40 TMU, SD=15.365 TMU). The analysis between the two groups of paper-based and IT-supported work instructions revealed a significant difference (M=106.91 TMU, U=1,259.000, $p<0.05$). The analysis regarding the three groups of work instructions exposed a significant difference (H=50.530, $p<0.05$). The usage of the iPad resulted in the fastest information processing times. The analysis between the IT-supported instructions revealed as well a significant difference (M=72.97 TMU, U=110,000, $p<0.05$). The amount of effort of information processing times of the iPad was more efficient, i.e. resulted in a lower value in TMU compared to the Google Glass.

In Figure 5, the diversification of the values of the information processing times of the three applied work instructions are visualized. The boxplot of the paper work instruction shows the largest variance as well as the highest mean of the values. The boxplot of the iPad has the lowest mean value, the one of the Google Glass the smallest variance.

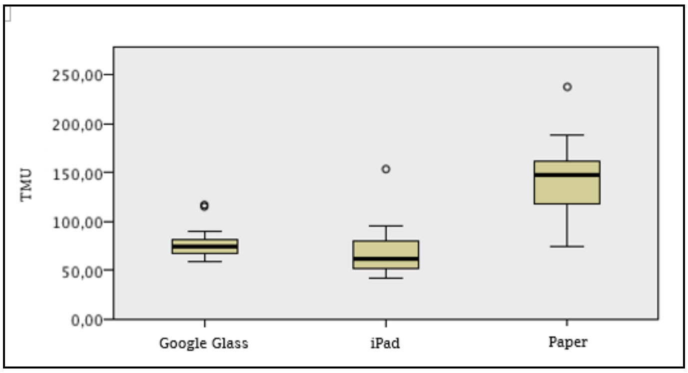


Fig. 5. Boxplot of the information processing times.

B. *Task completion times*

Considering the task completion times, the analysis of the three work instructions revealed a significant difference (H=21.99, $p<0.05$). The application of the iPad was faster (M=4.88 min., SD=0.826 min.) compared to the paper instructions (M=6.08 min, SD=1.169 min.) and Google Glass (M=5.04 min., SD=0.798 min.), whereby the IT-supported work instructions did not differ significantly among each other (z=0.674, $p>0.05$). Figure 6 shows the value diffusion of the three used work instructions. The boxplot of the paper work instruction shows the largest variance and highest mean value, followed by the Google Glass and the iPad. The boxplot of the iPad shows a higher variance compared to the Glass, but the majority of the values is located at lower part of the boxplot.

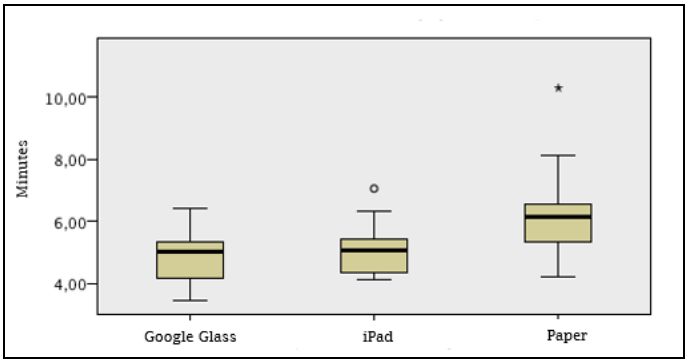


Fig. 6. Boxplot of the task completion times.

C. *Load test using NASA-TLX*

The comparison of the load test, using the NASA-TLX questionnaire [20,21], revealed a significant difference between the different work instructions (H=9.282, $p<0.05$). The emerging stress using the Google Glass (M=41.83, SD=20.55) was rated higher compared to the application of the iPad (M=22.6, SD=13.47) or paper work instruction (M=32.73, SD=18.97). The comparison of the three applied work instruction is shown in Figure 7. The boxplot of the Google Glass shows the largest variance and mean value, followed by the paper work instruction and the iPad. The variance of the iPad is significant lower compared to the other two.

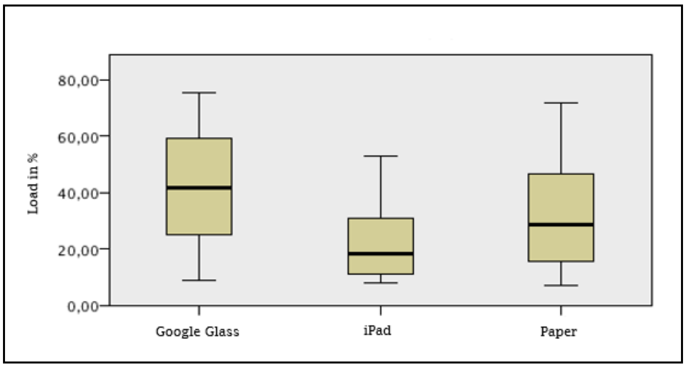


Fig. 7. Boxplot of the NASA-TLX values.

D. *Assessment of the work instructions*

The assessment of the different applied work instructions focused on the following three criteria: Ease of use, level of satisfaction and evaluation of performance. The analysis of the ease of use revealed, that there is no significant difference between the application of the three work instructions (M=4.194, U=774.000, $p>0.05$). For the IT-supported systems, the analysis showed a better evaluation result for the iPad compared to the Google Glass (M=4.213, U=56.000, $p<0.05$) regarding the ease of use. Considering the level of satisfaction, the analysis showed again no significant difference between all work instructions (M=4.10, U=680.500, $p<0.05$). Comparing the IT-supported instructions in this group, the iPad was rated again better compared to the Google Glass (M=4.21, U=35.000, $p<0.05$). The evaluation of the performances of each trial showed a significant difference (M=3.98, U=535.000, $p<0.05$) in favor of the iPad compared to the paper-based and Google Glass work instructions. Among the IT-supported systems, a clear significant difference exists in support of the iPad (M=4.21, U=63.000, $p<0.05$).

VI. DISCUSSION

The results of the user study show that the phases of information processing can be assessed by means of basic motions and the quantifiable time unit TMU. Based on the performed motion analysis, the potential of a workplace for the application of IT-systems can be assessed. Further, the specific type of an IT- system can be determined, which might be well suitable for the examined workplace. The overall results of the study show that the values of the information processing phases of the IT-systems are significant lower compared to the paper work instruction and therefore indicate the more efficient assistive system for this specific workplace. Moreover, the outcome is supported by the comparison of the task completion times, which highlights the application of the tablet as the assistive system with the best performance. That might be caused by the increasing application of these kinds of systems in the daily life and in private environments.

Regarding the IT-systems, the participants might be acquainted with the tablet system and present a higher technic affinity compared to the IT glass. However, the obligatory wearing of safety gloves during the user study made the input operations on the small and sensible control panel of the Google Glass more difficult. This influenced the outcome of higher information processing times and a lower assessment of the system by the participants.

In general, the results of the study show the effective and beneficial application of IT-systems as well as an evaluation method to prove the potential of workplaces regarding different forms of assistive work instructions. An internal validity of the results is given as the same designed instruction layout was used for the paper-based, tablet and glass instructions. The general validity might vary due to the diversifying paper instructions in different areas of industry and production. Depending on the workplaces, the work instructions can differ between only text-based, simply picture-based, or a combination of both. Regarding the evaluation of the information processing values using the MTM method, the general validity is given as the MTM method is a standardized motion analysis with clear defined requirements, fixed time values, terms and conditions.

VII. CONCLUSION

In this paper, we assessed the information processing values of different instruction systems at a workplace in order to establish an evaluation method for the potential identification of IT-systems. We compared the information processing values between an IT glass, a tablet and a paper work instruction at a manual work process to show that test persons without having prior knowledge in this field are able to perform this work task when being supported by different types of work instructions. Considering the motion analysis, the results showed a significant difference between the applied work instructions. The determination of mechanical and information phases, followed by the analysis of each manual operation based on its basic motions, constitutes an efficient evaluation base to determine the need of IT-systems at a workplace for information retrieval. For example, the results showed a lower value for the time used for the information processing phases applying the tablet-based work instructions, followed by the IT glass and the paper work instruction. The results of the task completion times, the NASA-TLX and the assessment of the systems support the outcome of the motion analysis, i.e. the tablet is the most efficient assistive system for this given work situation.

In future work, we want to investigate the systematic of assessing the information processes using the MTM method in a real production environment, with experienced employees and at a workplace, which is largely independent of a cycle-based production and non-repetitive tasks, e.g. the maintenance or machine setting sector.

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