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Efficient motion analysis of IT support for information retrieval at manual workplaces

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Abstract

Within the context of the “Industrie 4.0” initiative, workers should be enabled by information technologies to extend their abilities to handle a wider range of work processes. However, such information technology also requires additional workload, which is not clearly measurable yet. This paper thus introduces a concept of an extended application of the MTM method to measure and analyze the information retrieval phase and to also provide a platform to compare different smart devices for their suitability to the current task at hand. Finally, the paper briefly shows the current evaluation processes at a German car manufacturer.

Keywords: Motion analysis; Wearables; Objective measurement; Process optimization; Industrial engineering; Methods-time measurement (MTM)

1. Introduction

The industrial sector is confronted with a rapidly changing economic environment. Due to the globalization, smaller transport costs and profitability pressure, the companies need to customize their products for the individual consumer [1]. In the automobile industry, the workers thus face an increase in the level of complexity of production facilities due to the implementation of robots, the increase of car model variants, and the amount of processed data and information along the whole assembly line [2,3]. Nowadays, the production facilities are controlled by classical visualization systems of the processes in form of diagrams, graphs, lists, or simple 2D images, to support the worker in the task at hand [4]. However, within the context of the ‘Industry 4.0’ initiative, cyber-physical systems should provide a close connection between real worlds, such as the production processes and its digital counterpart (digital shadow or digital twin), also integrating the human operator. Today, many approaches exist to use this digital twin to support the worker by new instruction means. However, there is neither an evaluation of which work processes are in general suitable for such an IT-guidance of the workers, nor is there a reproducible comparison of IT-devices for the user to interact with the digital shadow.

This paper thus introduces a new concept to use the established MTM method for an evaluation of a work processes’ information retrieval phase, as well as for a comparison of used IT interaction devices. After an overview on related work in this field, this paper introduces the basic concept of MTM analysis for the information retrieval phase. Finally, the remainder of the paper introduces an use case at a German car manufacturer and concludes with an outlook on future work.

2. Related Work

For the evaluation of manual work processes on computers, one of the first methods for motion analysis was launched by Card et al. [5,6] in the context of evaluating the performance times. The method focusses on the time an expert user needs to perform a task on a given computer system. Since the model counted keystrokes, it was named Keystroke-Level-Model (KLM). Besides measuring the task

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completion times, the model focuses on the product at hand and does not include the information retrieval processes. Further research in this field is presented by Funk et al. [7,8] with the General Assembly Task Model (GATM), which differs between task-dependent and task-independent motions. Information processes, in particular cognitive processes, are not measured explicitly since they are seen as already being included in each individual process component.

Based on the existing assessment methods, manual work tasks can be evaluated, improved, modified and classified. A widely used and prominent assessment method is the Method-Time Measurement, as the so-called MTM. The classical MTM transcribes work processes based on standardized work descriptions with predetermined task completion times for five basic interaction modules, such as reaching, grasping, releasing, moving and positioning [9]. In the automotive industry, MTM is commonly used to improve working stations regarding ergonomic issues, and to determine the overall potential of the complete assembly line [3,10]. With the help of MTM, procedures can be systematically organized, divided, and influencing factors can be visualized. Within a production organization, MTM can be applied as the development standard and basic tool for measurements, comparisons and changes at all process levels.

Besides the basic MTM, several variants were developed to group core tasks, which are frequently applied. For example, MTM-UAS is used for order-specific tasks with repeating character, and MTM-MEK for non-cyclical workflows and work stations with low levels of routines. The modules of MTM-UAS and the standardized basic procedures of the MTM-MEK describe aggregated groups of typical work processes like screwing applications, treating of surfaces, inspecting and measuring etc. The analyst selects a variant based on the specific process type 1-3 [11]. In Table 1, the process types are listed in a shortened version illustrating the specific characteristics and present variants of MTM.

Table 1. MTM process types [11].

Characteristics	**Proc. Type 1**	**Proc. Type 2**	**Proc. Type 3**
Cycle	Permanent, repetitive cycle	Restricted long-term repetitive cycles	Non-cyclical work flows
Information of process	Motion sequence	Partial process	Overall process
Working situation	Defined products	Defined spectrum of products	Any processes and products
Supply principle	Delivery principle	Pick-up principle with delivery	Pick-up principle
Distribution of operation	Low	Medium	High
Level of method	High	Medium	Low
MTM type	MTM-1	UAS	MEK

Among others, the main targets concerning the application of MTM are the avoidance of unnecessary movements and processes, to clarify non-transparent tasks, to provide cross-sectional data for the complete company, and to ensure an optimal application of used operating materials [12,13]. With the integration of the human being into the evaluations, the core focus is primary on physical strain, manual procedures and key performance indicators. Thus, MTM and other objective methods have in common that the information retrieval, processing and transfer are not considered in detail or subsumed in the existing classes [14]. However, human beings only have a limited mental processing capability, which will contribute the more to the overall completion time, the more information has to be processed during the task at hand [15]. With the increasing complexity of manual work processes due to the large amount of product variants, also cognitive processes in the context of an optimized worker instruction become more and more important. It was stated in [16] that the cognitive processing time is neither constant nor independent of the work sequence. Here, the mental information processing time was researched more in detail, depending on the manual task at hand, its position in a sequence of operations, and the kind of information representation. With the increasing amount of information that is required, also the time for information retrieval becomes more important and thus needs to be considered more in detail.

In future, it will not only be the cognition time during the manual work process that is important, but also all efforts that are required to interact with the digital content. It is thus not only the cognition, but also manual work processes that are required to find and select the correct information. Thus, this paper will introduce an approach how this information phase can already be considered during the planning or evaluation phase of a work place. The suitability of a workplace to be supported by information technologies will be evaluated using the established MTM method that is supplemented by an information retrieval phase.

The following chapters will describe more in detail how workplaces can be evaluated. The need for a support by information technologies and how IT-devices can then be compared to each other will be regarded. The analysis is done by considering the manual operation steps that are required for information retrieval and information interaction.

3. Concept

Working places, which shall be supported by information technologies, can be assessed by using the MTM method as described below. The new intervals for information retrieval are called in the further course “information window”. Depending on the task at hand, the length of this information window can differ significantly. It might be very short for a manual operation at an assembly line, if the worker just has to look at a label or a monitor. In other cases, it might take a considerable time, e.g. for a maintenance task at a machine tool, where the worker has to read several information from handbooks or the machine control itself. The lengths of such information windows and their frequency of occurrence thus give a first hint, where the use of supporting information technology might be feasible. However, the length and the frequency are not sufficient, since they do not give indications about how the information is retrieved and how the user will interact with the information source.

Besides acquiring the typical mechanical units of action of the actual task, e.g. reaching, grasping etc., the recordings will also visualize other operations in the information window, which are related to information retrieval and interaction. Within this information window, new action modules will emerge with the application of IT-devices and need to be transferred into the MTM concept. We thus propose the following basic elements for the usage of IT-devices and describe manual operations with exemplary devices, such as Google Glass or the Microsoft HoloLens:

- Clicking or touching: This is the most basic element for selecting digital information. When looking at this element even more in detail, it again consists of already existing basic motions, such as reaching (e.g. for the mouse), grasping (e.g. the mouse), moving (e.g. the mouse), positioning (e.g. the cursor) and releasing. The same can be applied on an IT-glass, e.g. the Google Glass. For example moving the finger, here seen as the working tool, to the glass, contact the surface and release, i.e. give up the contact.
- Scrolling: For selected information, longer texts might require a vertical and/or horizontal displacement of the visual text. Scrolling might either use a dedicated key (→ "typing") or is otherwise always accompanied by the manual operation "clicking". In the case of using the IT-glass Microsoft HoloLens, the scrolling can be described as follows: Moving the finger, seen as the working tool, to the hologram, click, but keep the finger in contact to activate the display. Then move the hand downwards or sideward to scroll in a specific direction.
- Typing: For entering information, but also for other actions like scrolling or clicking, e.g. a keyboard could be used. Again, this element will consist of reaching (e.g. moving the hand to the keyboard), positioning (e.g. the finger on a certain key), and releasing. Tiring up with the previous example, the typing using a Microsoft HoloLens comprises the moving of the finger to a holographic keyboard, clicking on a certain holographic key and release.
- Perception: This is the actual perception time, where the user reads a text or follows a video or an audio instruction. The perception time is also applied, when focusing displayed pictures, matching the real object with the displayed picture or checking specific monitoring features.

These basic operations exist for most of the IT-devices without reference to the underlying technology. Based on this, IT-devices can be evaluated and compared in the future referring to their suitability for a given work process, regardless whether monitors, data glasses or tablets are considered. For example, if a job task requires a high level of information retrieval and an information technology should be implemented, the evaluation via the MTM shows which type of device, e.g. data glass or tablet, is suitable for this task. If a simple information retrieval matters, e.g. a tablet instead of a head-mounted display is already sufficient. In Table 2, three exemplary manual operations analyzed with the MTM method are shown that are emerging with the application of IT-devices.

Table 2. Basic motions regarding IT-devices.

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 touch point until stop (A). Contact the surface (G5) and release the finger, 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 6cm forwards (M), 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

4. Evaluation Method for IT-Systems

If a potential for IT-supported information retrieval is present at an observed working station, the MTM analysis serves as decision basis for the determination of the most suitable IT-system. The presented concept works as follows: First, the work processes are divided into phases of "mechanical work" (already being analyzed with the traditional MTM) and "information processing". The latter phase is further analyzed using the standardized MTM method to retrieve time values for further calculations.

As shown in the previous chapter, the basic motions of the MTM method, i.e. reach, grasp, move, position, release, and so on, can be similarly transferred to the phases of the information processes. 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, these basic motions do not appear, respective the touch is used to select a certain point on the display surface. The results can be used to make a decision if an IT-support at the investigated workplace is feasible.

In Figure 1, the appearing basic motions in the phase of the information processing phase are displayed, which emerge by reading an instruction and matching the information of an object.

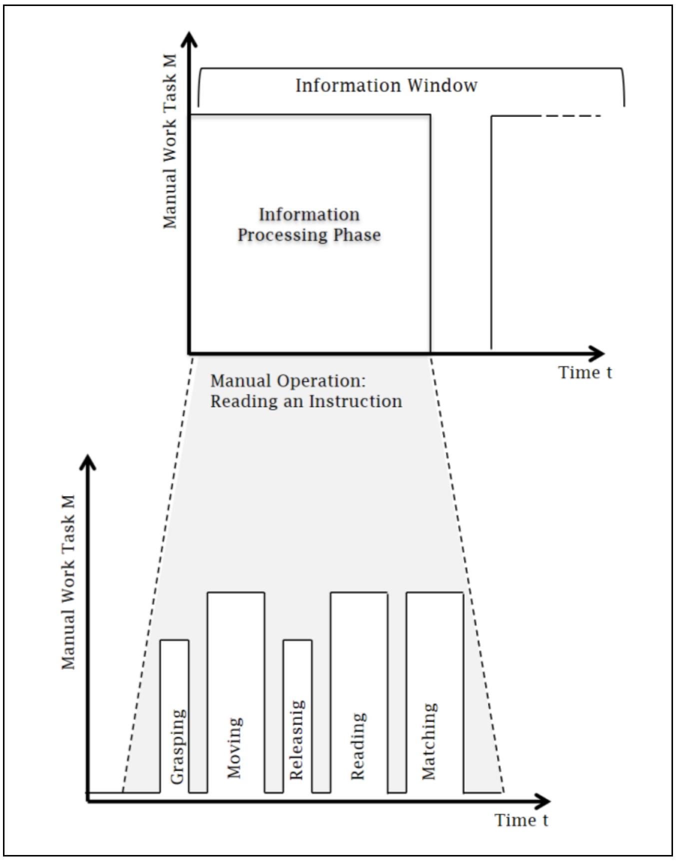

Fig. 1. Example of basic motions during the information processing phase.

Each phase of information processing can be narrowed down to the basic motions and analyzed in that way.

5. Use Case

A user study was performed to verify the previous described theoretical approach. Following a within-subject design, forty test persons performed a manual assembly task two times with different assistance systems, i.e. a paper-based work instruction, an IT-glass and a hand-held device. The applied IT-supported technologies were the Google Glass and the iPad. The setup of the manual assembly tasks included an usual working process of fitting, fixating and screwing together of sheet metal parts on a special appliance of the car body construction of a German automobile manufacturer. The assessed variables include the relevant information processes evaluated with the MTM method, the task completion times, the perceived cognitive load assessed with the NASA-TLX questionnaire as well as the assessment questionnaire for assistive systems. To prevent a learning effect, the usage of the paper work instruction and the IT-systems was exchanged for the complete group of test persons, i.e. the half of the group started with the paper work instruction, the other with the digitalized assistive 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.

During the motion analysis, the recorded performances were analyzed with the MTM method and divided into the phases of mechanical work and information processes. Afterwards, the achieved results were analyzed with the help of SPSS regarding significant differences in the phase of information processes of applying the different work instructions. The SPSS testing included the Mann-Whitney-U-Test for two different groups, i.e. the paper-based work instructions and the IT-supported instruction. Further the Kruskal-Wallis-Test was applied to compare three groups, i.e. the paper work instruction, the IT-glass and the hand-held device.

The results of the SPSS testing showed that the information processes of the paper work instruction (M=140.85 TMU, SD=32.858 TMU) include 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 iPad (M=72.96 TMU, SD=26.29 TMU) or the Google Glass (M=77.40 TMU, SD=15.365 TMU). The analysis of the paper-work instruction and in general the IT-supported systems, the comparison showed a significant difference (M=106.91 TMU, U=1,259.000, $p<0.05$). Regarding the three types of work instructions, the test revealed a significant difference (H=50,530, $p<0.05$). The application of the iPad resulted in the fastest information processing times. Compared to the Google Glass, the IT-systems showed as well a significant difference among each other (M=72.97 TMU, U=110,000, $p<0.05$). The iPad was more efficient due to a lower value in TMUs.

The results of the cognitive load test, using the NASA-TLX questionnaire, showed a significant difference between the work instructions (H=9.282, $p<0.05$). The stress load 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 the paper-based work instruction (M=32.73, SD=18.97). The assessment of the work instruction followed three criteria: Ease of use, level of satisfaction and evaluation of performance. Regarding the ease of use, the analysis showed no significant difference between the applied work instructions (M=4.194, U=774.000, $p>0.05$). Considering the IT-supported systems, the analysis showed a better evaluation for the iPad (M=4.123, U=56.000, $p<0.05$). The level of satisfaction revealed again no significant difference between all applied work instructions (M=4.10, U=680.500, $P>0.05$). The analysis of the IT-supported systems showed a better evaluation result for the iPad compared to the Google Glass (M=4.21, U=35.000, $p<0.05$). Considering the performance, the analysis showed a significant difference (M=3.98, U=535,000, $p<0.05$). The iPad was rated best. Among the IT-supported systems, the analysis showed a significant difference in favor of the iPad compared to the Google Glass (M=4.21, U=63,000, $p<0.05$).

6. Summary and Future Work

In this paper, a conceptual approach is introduced to objectively evaluate the IT-supported information retrieval in working processes. By dividing the tasks of a dedicated working station into the phases of mechanical work and information processing and further analyzing the latter with the help of the MTM, an assessment platform is given that allows evaluating the potentials of various supporting information technology. The presented procedure is easily applicable, when MTM is already established in the company. The theoretical approach was analyzed with the help of the user study at a German automobile manufacturer, which confirmed the idea of the extended application of the MTM method. Within the results of the three applied work instructions, the iPad could be identified as the best suitable IT-supported system for this specific working station based on the assessed information processes. The findings are supported by the results of the cognitive stress load test and the subjective evaluation of the test persons regarding the applied work instructions. It is shown that widely used methods can be modified regarding the technological change in industrial sectors due to the digitalization and fourth industrial revolution.

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