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Derivation Of MTM-UAS® Analyses From Virtual Reality Tools Using MTMmotion®

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Abstract

Designing human work in a productive way plays a vital role in maintaining competitiveness of industrial companies. In order to fulfil this task, practitioners can use different methods to describe, analyse and design work processes. One widely used method is the process building block system MTM-UAS®. Analysing the work processes manually (with MTM-UAS® or other methods) requires manual effort for data collection and interpretation of the method user. Due to this fact, not every industrial company has the capacities to design work productively.

One possibility to reduce this effort is the automatic interpretation of digitized human motion data. Motion data describes human movements and includes, for example, distances covered, joint positions or object interactions. The technology virtual reality is capable to generate this movement data. Thanks to the advances in the technology in recent years, it can be used in a large number of workplaces.

This article presents an approach how one can use the motion data of virtual reality tools to derive an automated MTM-UAS® analysis. The technology thus reduces the analysis effort significantly and offers the possibility of expanding the areas of application. First, the article explains the process building block system MTM-UAS®. It then explains the virtual reality data that is needed to automatically generate MTM-UAS® analyses and that can be generated by the virtual reality tool. It then shows how the data is translated into a valid MTM-UAS® analysis. The Steps are explained using an exemplary workplace that was modelled using a virtual reality tool.

The article concludes with an outlook on how this approach can be transferred to other technologies like human simulation. With such a transfer it is conceivable to design a higher number of workplaces in a productive way and thus to maintain the competitiveness of industrial companies.

Keywords

digital human motion data; human work design; automated process analysis; MTM-UAS®; MTMmotion®

1. Introduction

One key factor for being competitive as an industrial company in international markets is the cost of production. One relevant portion of these costs are labour costs, especially for productions with a high share of manual processes. Thus, describing, analysing, and designing manual work processes in a systematic way is an important task in every Industrial Engineering department. By designing productive and healthy workplaces, companies can reduce the cost of production and make sure that the time of their employees is used for meaningful activities.

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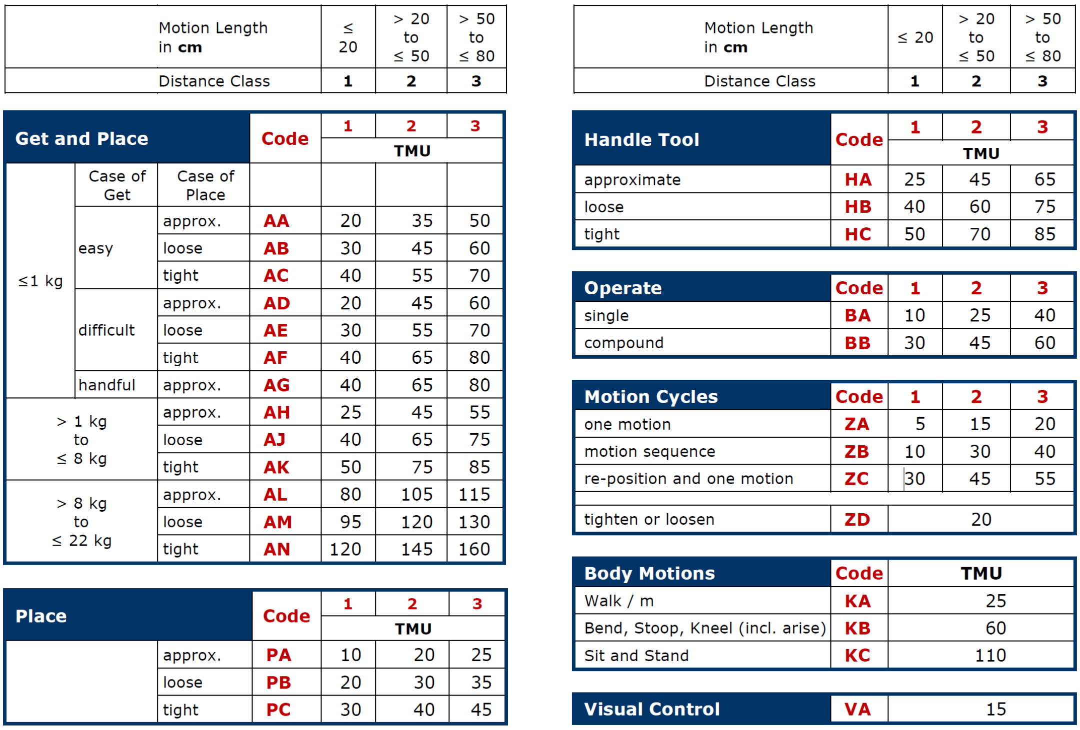
There are multiple methods to describe and analyse work processes (i.e. REFA [1], MTM [2, 3, 4] or Work Factor [5]). One established method, especially in the automotive sector, is the process building block system MTM-UAS® [2, 6].

2. The process building block system MTM-UAS®

The process language MTM and its different process block building systems like MTM-UAS® are characterized by its own syntax and semantics. This provides the vocabulary as well as the grammar to describe work processes in an understandable and standardized way [2, 3, 4, 7].

The notation of each MTM process building block is characterized by multiple language elements [2, 3, 4, 7]. The code is the “name” or designation of a building block. For example, the code *KA* in MTM-UAS® describes the time relevant movement of the trunk. It is then characterized by a defined beginning, description and ending. The building block *KA*, for example, starts when the trunk begins to move and ends when the target location has been reached. Another language element are the influencing variables that further describe each building block [6].

In addition to these descriptive language elements, each building block has an evaluated standard time value. For the building block, that standard time is 25 TMU (Time Measurement Units, 25TMU equal approximately 0.9 seconds). These standard times are globally standardized and widely accepted in multiple industries (i. e. automotive or white goods). By describing a whole work process with the corresponding building blocks, the entire required time for that process can be calculated [6].



Motion Length in **cm**	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	**1**	**2**	**3**

Get and Place			**Code**	**1**	**2**	**3**
				TMU		
	Case of Get	Case of Place				
≤1 kg	easy	approx.	**AA**	20	35	50
		loose	**AB**	30	45	60
		tight	**AC**	40	55	70
	difficult	approx.	**AD**	20	45	60
		loose	**AE**	30	55	70
		tight	**AF**	40	65	80
	handful	approx.	**AG**	40	65	80
> 1 kg to ≤ 8 kg		approx.	**AH**	25	45	55
		loose	**AJ**	40	65	75
		tight	**AK**	50	75	85
> 8 kg to ≤ 22 kg		approx.	**AL**	80	105	115
		loose	**AM**	95	120	130
		tight	**AN**	120	145	160

Place		**Code**	**1**	**2**	**3**
			TMU		
	approx.	**PA**	10	20	25
	loose	**PB**	20	30	35
	tight	**PC**	30	40	45

Motion Length in **cm**	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	**1**	**2**	**3**

Handle Tool	**Code**	**1**	**2**	**3**
		TMU		
approximate	**HA**	25	45	65
loose	**HB**	40	60	75
tight	**HC**	50	70	85

Operate	**Code**	**1**	**2**	**3**
single	**BA**	10	25	40
compound	**BB**	30	45	60

Motion Cycles	**Code**	**1**	**2**	**3**
one motion	**ZA**	5	15	20
motion sequence	**ZB**	10	30	40
re-position and one motion	**ZC**	30	45	55
tighten or loosen	**ZD**	20		

Body Motions	**Code**	**TMU**
Walk / m	**KA**	25
Bend, Stoop, Kneel (incl. arise)	**KB**	60
Sit and Stand	**KC**	110

Visual Control	**VA**	15

Figure 1 MTM-UAS®-Data Card Basic Operations

Figure 1 shows all the process building blocks (here: basic operations) for MTM-UAS®. They are divided into *Get and Place, Place, Handle Tool, Operate, Motion Cycles, Body Motions and Visual Control*. The Figure also shows the central influencing factors for these motions like the *Distance Class* or the *Case of Place*.

3. Exemplary workplace

To demonstrate the interface data as well as the results of the translation algorithm, an exemplary workplace will be used. In this case, the worker preassembles a module for a dish washing machine, which consists of a component carrier, two pumps, several hoses, screws, and other small parts. The complete process has a duration of about 2 minutes, but this article focuses on the last step of the process, which is fastening the pumps with screws.

The process was modelled in a virtual reality (VR) tool developed by the company LIVINGSOLIDS [8]. This VR solution uses a VR headset and handheld controllers. To allow for tracking the body motions it also uses marker-based motion capture cameras. With that VR setup, a worker assembled the product in the virtual reality application.

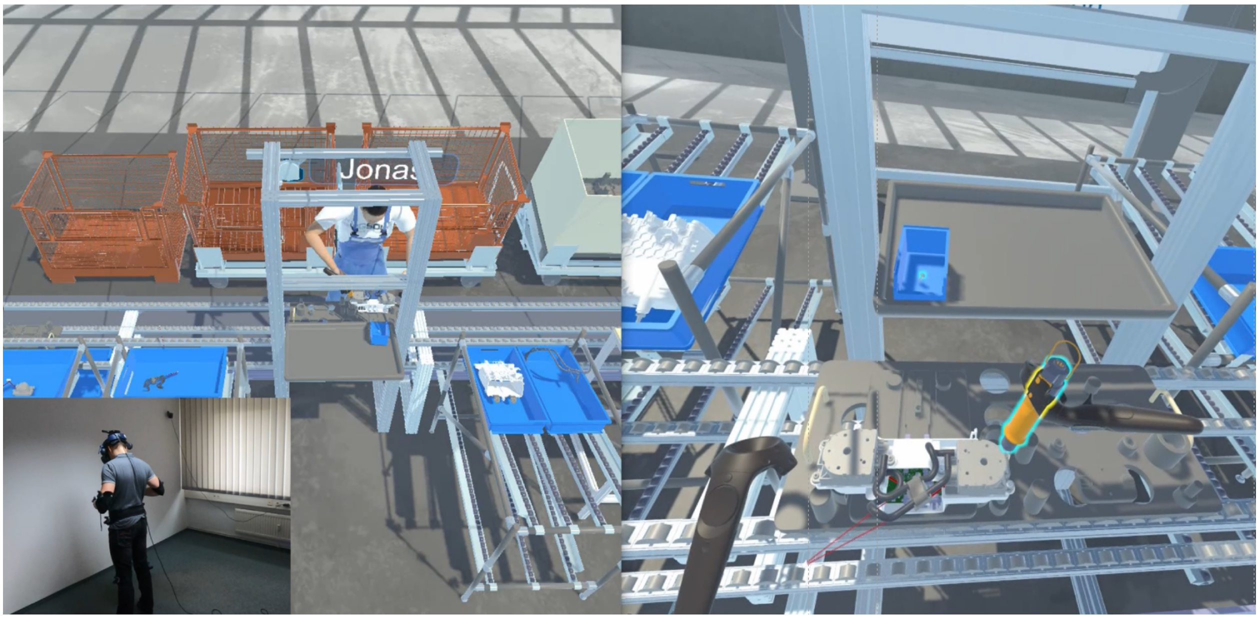


Figure 2 views of the LIVINGSOLIDS virtual reality tool

Figure 2 shows several images of the usage of the software during the recording. On the lower left, one can see the worker wearing the VR components. Above this is the view of the software on the main computer, while the right side shows the view of the worker. In the shown moment, the worker is assembling a screw using an electric screwdriver.

4. Translation of virtual reality motion data using the MTMmotion$^{\circledR}$ interface.

To realize the translation from the recorded data in the shown example to valid MTM-UAS$^{\circledR}$-analyses, the developed approach utilizes a uniform interface for motion data. The principle is depicted in Figure 3. Central element is the interface. It describes digital motion data in a way that allows digital tools like the VR solution by LIVINGSOLIDS to deduce it from their own inherit data structure. Furthermore, the data consists of all the necessary information to derive valid MTM-UAS$^{\circledR}$ analyses. The data is described in chapter 4.1.

The next part of the approach is the mentioned deduction of the interface data from the VR software. In the shown case, LIVINGSOLIDS developed those algorithms and tested them in cooperation with the MTM ASSOCIATION. The last part is the derivation of a valid MTM-UAS$^{\circledR}$-analysis from the interface data. This process is described in chapter 4.2.

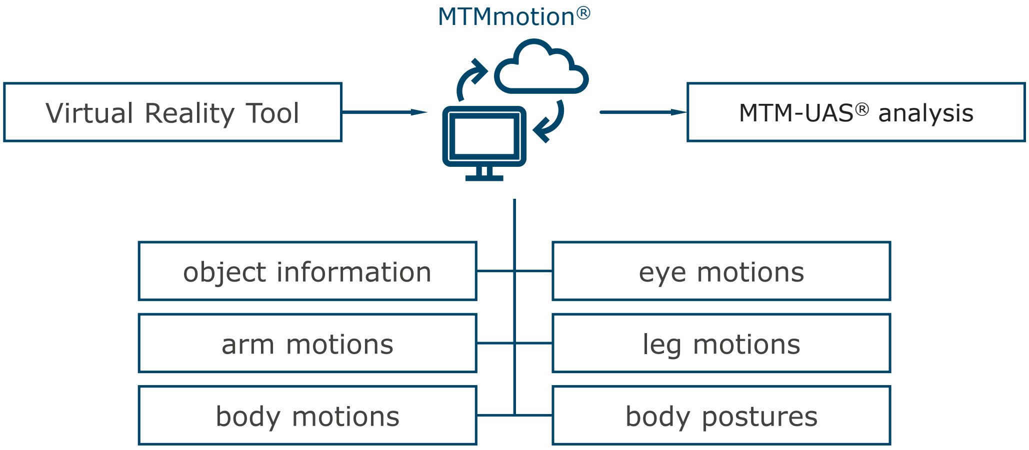


Figure 3 Derivation of MTM-UAS®-analyses form VR tools using MTMmotion®

4.1 MTMmotion® interface data

The interface contains all relevant data needed to describe the relevant movements and postures performed by an employee when executing a work task as well as the objects with which he/she interacts. It contains an object list and six motion channels that describe human work processes:

1. Object List
2. Channel Body Motions
3. Channel Arm Motions
4. Channel Leg Motions
5. Channel Eye Motions
6. Channel Body Posture
7. Channel Arm Posture

The Object List describes the objects being handled by the worker and their relevant values such as weight or measurements for a more specific description of the object. The Motion Channels (Body, Arm, Leg and Eye) describe the movements that are performed by the worker. The following channels depict the posture of the worker during his work task. Following, only the object list and the arm motions are shown for the example workplace. They contain the most relevant information for manual work tasks.

Table 1 MTMmotion® data – object list

object id	**object type**	**weight [kg]**	**dimensions [mm]**	**flexible**
1	screw	0.02	5x12x12	no
2	screwdriver	1.2	150x50x80	no
3	hose	0.2	10x10x100	yes

Various object information is required to derive MTM-analyses (see Table 1). *Weight, Height, Width,* and *Length* describe the physical properties of the object. In general, the larger or heavier an object is, the more difficult it is to handle and thus, the MTM standard time is higher. *Flexible* is another further physical property that can make the handling of the object more difficult.

In the exemplary workplace several objects are described in the object list. For the presented steps of our process, three objects are used. Screws and a corresponding screwdriver to assemble the screws and the hoses.

Table 2 MTMmotion® data – arm motions

time start	time end	object ID	side	arm motion	supply	usage type
51.0	51.5	2	right	ObtainObject	separated	-
51.5	52.5	2	right	MoveObjectTo OtherPosition	-	-
52.5	56.8	2	right	HoldObject	-	-
52.6	53.6	1	left	ObtainObject	clustered	-
53.6	54.4	1	left	MoveObjectTo PointOfUse	-	-
54.4	56.8	1	left	UseObject	-	place
56.8	57.8	2	right	MoveObjectTo PointOfUse	-	-
57.8	61.7	2	right	UseObject	-	screw in

Table 2 shows the necessary information for the channel arm motions. To describe the arm movements, it is important to know what type of movement (*motion*) is performed by the employee. The motions are differentiated according to whether an object is obtained, moved, used or held. The *Usage Type* differentiates the motion type *UseObject* further, because for most objects there are different ways to use the object. A screw could – at its point of use – be screwed in or inserted or just placed on a screwdriver tip. Additionally, object usages generally follow motion trajectories dictated by the object, while the other motion types can usually follow any trajectories chosen by the employee. As an example, the screwdriver can be brought to its place of use via multiple valid movement paths, but the insertion of the screw with the screwdriver and the following screwing process are predetermined by the component's geometry.

For each motion, various additional influencing variables are important to describe the individual movement. For example, it is relevant which arm (*side*) performs the movement. In addition, the *start* and *end time* of the movement are necessary to determine if it takes place at the same time as the movements of other body parts. There is also motion specific information like the *supply* for the motion type *ObtainObject*. It describes if the object is picked up from a box with several object (*clustered*) or if it is *separated*.

In the example workplace the worker firstly obtains the screwdriver, which hangs separated, with his right hand and moves it into the core working area. He then holds the screwdriver in position while he picks up a screw out of box full of screws with his left hand. He brings the screw to the screwdriver (point of use) and places the screw on the screwdriver. Lastly, he moves the screwdriver (with screw) to its point of use (the pump) and screws in the screw.

4.2 Derivation of MTM-UAS analyses®

The translation of the interface data into MTM analyses is the last step of the approach. This process consists of several steps:

1. Input data validation: Firstly, the algorithm checks if the input data is meaningful. This means that it checks if the handling of objects follows a meaningful order. For example, the algorithm would detect an error if objects were moved that were not obtained before.
2. Input data completion: In the next step the algorithm also checks whether the input data is complete. Although the interface contains all the information that is needed for a complete MTM-UAS® analysis, it is not necessary to put in every non-essential information. If this kind of information is

missing the algorithm fills it with standard data. For example, the algorithm would add an average screw weight if it wasn't given by the VR tool.

3. Translation into building blocks: One central step in the algorithm is the translation of the various motions into building blocks. In the case of MTM-UAS®, it combines the motions into basic operations. Here, it would combine all motions in Table 2 that relate to the screw into one *Get and Place*.
4. Combination of different body parts: The last step of the algorithm matches each motion channel with the other motion channels to check if there are parallel motions. If that is the case, the MTM rules are applied to check if they can be performed simultaneously in industrial workplaces. For example, the algorithm would check if the screw can be obtained and placed, while the other hand holds an object. In that case, it does not result in a conflict.

The result is of these four steps is a valid MTM-UAS® analysis that matches the interface data supplied by the VR tool. Table 3 shows the result for the example workplace. The analysis describes the assembly of the first two screws for the described work process. The result is a total standard time of 275 TMU (approx. 10 seconds).

To compare the results, an experienced MTM practitioner conducted a manual analysis using the video and the relevant object data as well as estimated distances. The automatically generated analysis from the VR input data matches the analysis without any differences.

Table 3 Automatically generated MTM-UAS® analysis

Description	Code	Q x F	TMU
Screwdriver into workspace	HA2	1 x 1	45
Place screw	AE2	1 x 1	55
Place screwdriver	PC1	1 x 1	30
Process time screwdriver	PTTMU	1 x 30	30
Place screw	AE2	1 x 1	55
Place screwdriver	PC1	1 x 1	30
Process time screwdriver	PTTMU	1 x 30	30
Sum	**-**	**-**	**275**

5 Conclusion and Outlook

5.1 Critical Discussion

The presented approach has shown good results for the first cases for VR technologies. However, there are some aspects that need to be discussed critically.

1. Completeness of VR data: Since the process relies on the shown data being transferred from the VR tool to the data interface, it is necessary that firstly, the tool can model said data in a VR simulation, and secondly, that the data is input correctly by the VR user. One example is the object data. If the simulation does not include object types or weights, the data cannot be translated, or the standard values provided by the algorithm are translated, which might not be correct for all cases.

2. Quality of the motion capture algorithm in the VR tool: To derive the correct process building blocks, the motions must be recorded properly by the VR tool. In the shown example case, all relevant motions were captured. The quality in a wide use must be checked in future cases.

3. Translation of motion data ‘as provided’: The approach translates the motion data without checking if it would make sense for the real product in a real production. That means that if the process is modelled wrong or unnecessarily complicated, the resulting MTM-UAS® analysis describes exactly that process. That’s why it will still be necessary that an industrial engineer checks the modelled process and the MTM-UAS® analysis.

When those aspects are properly addressed, the approach can help industrial engineers to plan workplaces in a modern and efficient way. If they use VR technologies, they will need little effort to also get valid MTM analyses. It will be easier for them to model different variants and simultaneously get valid process descriptions and analyses, which helps choosing the best variants or to identify optimizations.

The interface was developed to be accessible for all technologies that record or generate motion data. As different technologies yield different data types as well as qualities while recording or generating motion data the quality of the resulting MTM analyses might differ as well. However, the developed approach was designed to yield analyses matching the input data and thus, the success of the approach is not impacted by the quality of the input technology.

5.3 Outlook

To improve the approach and thus its usability, several developments are possible. Firstly, the approach will be tested on several additional workplaces in industrial companies. Secondly, other VR tools will be enabled to supply the interface data. Thirdly, other MTM process building block systems such as MTM-1® or MTM-MEK® will be implemented. These steps aim to advance the combined use of VR and MTM in industrial companies.

Since the interface data is designed in a way that does not depend on the VR technology, it is possible to transfer the approach to other technologies that use digital motion data such as human simulation tools [i. e.] or motion capture suits [i. e.]. The transfer of this approach to other technologies would also offer starting points to develop interfaces that transfer motion data combined with process data from one technology to another.

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