MTM in Motion – Perspectives to Digital Work Design

Deriving MTM Analyses from Virtual Reality Tools

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1. Introduction

The cost of production is a key competitiveness factor for industrial companies in national and international markets. Labour costs are one relevant portion of these costs, especially for production sites with a high percentage of manual processes. Therefore, describing, analysing, and designing manual work processes in a systematic way is an important task in most Industrial Engineering departments. By mastering this task and 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.

There are multiple methods to describe and analyse work processes. Widely known methods to assess process times include REFA (REFA 1997), MTM (Antis et al. 1969; Bokranz/Landau 2012; Maynard et al. 1948) and Work Factor (Quick 1960). While there are multiple MTM methods to address the different types of production, one of the most established methods is the process building block system MTM-UAS® (MTM-Universal Analysing System; Bokranz/Landau 2012; MTM 2019).

The most recent process building block system is Human Work Design (MTM-HWD®, Finsterbusch 2016; Finsterbusch et al. 2019). It describes work processes not only from a productive standpoint, but also includes ergonomic factors to assure productive and ergonomic work in one step.

While the MTM systems can be used to systematically design work processes, they still require manual effort for data collection and interpretation of the method user. Due to this fact, not every company has the capacities to design work using MTM systems. One possibility to reduce this effort is the automatic interpretation of digitized human motion data.

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Motion data depicts human movements and postures and includes, for example, distances covered, joint positions or object interactions. One technology that is capable to generate this data is virtual reality. Thanks to the advances in the technology in recent years, it can be used in a variety of workplaces and with minimal training.

2. The process language MTM and the process building block system MTM-UAS®

The process language MTM and its different process building block systems like MTM-1®, MTM-UAS® and MTM-HWD® are characterized by their own syntax and semantics. They provide the vocabulary and the grammar to describe work processes in a standardized and understandable way (Antis et al. 1969; Bokranz/Landau 2012; Kuhlang 2018; Maynard et al. 1948).

The notation of each MTM process building block is characterized by several language elements (Antis et al. 1969; Bokranz/Landau 2012; Kuhlang 2018; Maynard et al. 1948). The code is the "name" or designation of a process building block. For example, the code *KA* in MTM-UAS® describes the movement of the trunk. It is also characterized by a defined beginning, description and ending. The building block *KA* begins when the trunk starts to move and ends when the target location has been reached. In other MTM systems, walking is indicated by corresponding codes. In MTM-1, for example, this would be a W (walk, MTM-1 2019; MTM-UAS 2019). The language elements also include the influencing factors that further describe each process building block (MTM-1 2019; MTM-UAS 2019). These factors generally include accuracies, distances, postures, and forces (Benter/Kuhlang 2019; Benter/Kuhlang 2021). In the example of walking, the most important influencing factor is the travelled distance.

In addition to these descriptive language elements, each process building block has an evaluated standard time value. For instance, the process building block *KA* has a standard time of 25 TMU (Time Measurement Units, 25 TMU equal approximately 0.9 seconds). These times are globally standardized and widely accepted in multiple industries (i.e., automotive, or white goods). By describing the whole work process with corresponding process building blocks, the entire required time for that process can be calculated (MTM 2019).

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 (MTM 2019)

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

3. Digital technologies and the need to develop MTMmotion®

Digital technologies are increasingly finding their way into all aspects of the working world. In the field of work design, this includes, among others, technologies that generate or record human movement data and then process it further. These include human simulation (e.g., ema Work Designer: imk 2023; Fritzsche et al. 2019), virtual reality (e.g., LIVINGSOLIDS 2022 or halocline 2023) and motion capture (e.g., XSens: Movella 2023).

With these technologies, human work can be designed in a targeted manner, especially if the work processes under consideration are systematically evaluated in terms of time and ergonomics. Classic methods of work design such as MTM and REFA (see chapter 1) are suitable for this.

For example, the software manufacturer imk has developed a solution for deriving MTM analyses from the human simulation tool ema Work Designer and evaluated it in cooperation with the MTM ASSOCIATION e. V. (Fritzsche et al. 2019; Benter/Kuhlang 2021; imk 2022).

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In addition to imk, other technology manufacturers are also interested in such solutions. MTMmotion® was developed to ensure that the developed solutions deliver valid, rule compliant MTM analyses and that all technologies have equal access to the MTM systems. Figure 2 illustrates this approach.

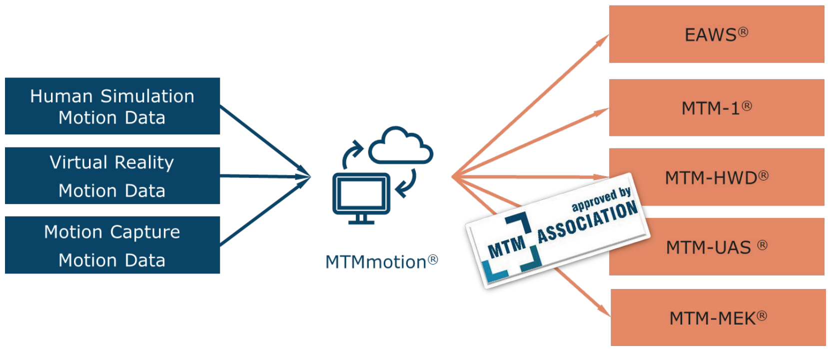

Figure 2: MTMmotion® – Technology independent MTM translation

MTMmotion® aims to act as an interface through which human movement data is translated uniformly (for all technologies) into correct MTM analyses. The integration of MTM enables technology users to carry out a targeted analysis and design human workplaces. It also fulfils the statutory mandate of the MTM ASSOCIATION e. V. to further spread the MTM methods, to ensure their correct application and it is awarded by the certificate "approved by MTM ASSOCIATION".

4. Exemplary workplace

An exemplary workplace will be used to demonstrate the interface data as well as the results of the translation algorithm. In the given example 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 assembly time of the complete workflow takes about 2 minutes, but this article focuses one of the last steps of the process, which is fastening the pumps with screws.

The whole workstation including all the necessary processes were modelled in a virtual reality (VR) tool developed by the company LIVINGSOLIDS (LIVINGSOLIDS 2022). This VR solution uses a VR headset and handheld controllers. To record the body motions, it also uses marker-based motion capture cameras. This VR setup was used to assemble the product in the virtual reality application.

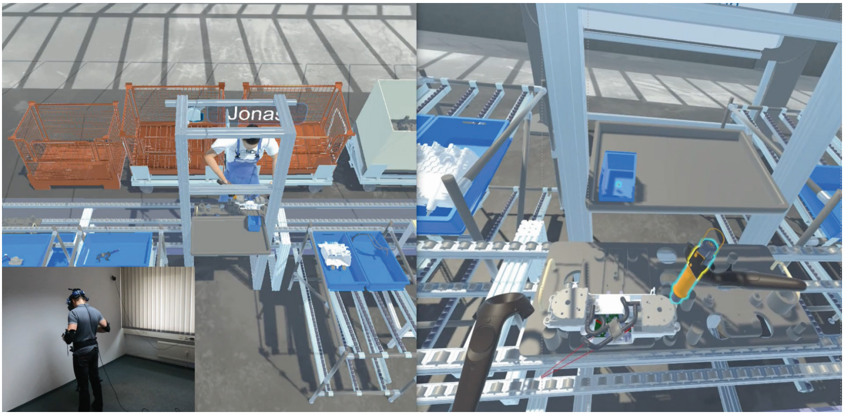

Figure 3: Views of the LIVINGSOLIDS virtual reality tool

Figure 3 shows several images of the software and the user while creating the recording. In the lower left, one can see the worker wearing the VR components. Above this is the central view of the software, while the right side shows the view of the worker. In the shown moment, the worker is assembling a screw using an electric screwdriver, which can be seen in the right picture.

5. Derivation of MTMmotion® data

5.1. General approach of MTMmotion®

The translation of the data generated by the VR software is realized by using MTMmotion®. At its core it consists of two elements. One element is a digital language to describe human work processes or a motion data interface. The other element are algorithms that translate the interface data into valid MTM analyses. The concept is illustrated in Figure 4.

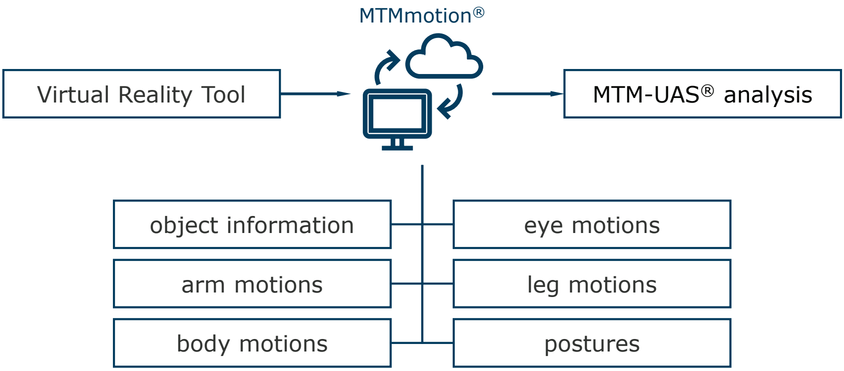

Figure 4: Derivation of MTM-UAS® analyses form VR tools using MTMmotion®

The interface describes digital motion data in a way that allows digital tools like the VR solution by LIVINGSOLIDS to deduce that data from their own inherit data structure. It also consists of all the necessary information to derive valid MTM analyses. The data structure is described in chapter 5.2. The deduction of the interface is different for each technology or software as their data architecture is different as well. In the shown use case, the algorithms to fill the interface were developed by LIVINGSOLIDS and tested in cooperation with the MTM ASSOCIATION e. V.

If a VR tool like LIVINGSOLIDS delivers the motion data to the MTMmotion® interface, the data is translated into valid MTM analyses. This process is described in detail in chapters 0 and 7.

5.2. MTMmotion® interface data

The interface consists of an object list and six motion channels that describe human work processes. The interface channels generally describe data over time. In this context, the data in these channels contain information about movements and postures. The object list and the channels are filled with all the relevant data needed to describe the movements and postures performed by an employee when executing a work task as well as the objects with which they interact.

The interface is structured as follows:

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

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 other two channels depict the posture of the worker during their work task. For the example workplace, the channels Object List and Arm Motions are crucial and will be shown in detail. They also represent the most relevant information for manual work tasks in general.

object ID	object type	weight [kg]	dimensions [mm]	flexible
1	screw	0.02	5 x 12 x 12	no
2	screwdriver	1.2	150 x 50 x 80	no
3	hose	0.2	10 x 10 x 100	yes

Table 1: MTMmotion® data – object list

Various object information is needed for the derivation of an MTM analysis (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 physical property that can make the handling of the object challenging. The table shows the three objects that are used for the presented steps of the process: Screws, hoses, and a screwdriver to assemble the screws and hoses, as well as an excerpt of their most relevant object information.

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: MTMmotion® data – arm motions

Table 2 shows the necessary information for the channel Arm Motions. An essential aspect of these motions is the type of movement (*motion*) with which the employee performs their tasks. They can be distinguished by whether an object is obtained, moved, used, or held. Additionally, the motion type *UseObject* can be differentiated further by the *Usage Type*, 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.

In the example workplace the worker first obtains the screwdriver, which hangs in a separated position, with their right hand and moves it into the main working area. They then hold the screwdriver in position while they are picking up a screw

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out of a box full of screws with their left hand. They bring the screw to the screwdriver (point of use) and place the screw on the screwdriver. Lastly, they move the screwdriver (with screw) to its point of use (the pump) and screw in the screw.

Each arm motion is further specified by various additional influencing factors to describe the individual movement of the employee. For example, it is relevant which arm (*side*) performs the movement. To understand the workflow, it is also vital to track the start and end time of the movements. This helps to follow the chronological sequence of operations as well as to determine if arm movements are simultaneously performed with movements of other body parts.

In addition to the influencing factors that are important for all arm motions, there is also motion specific information, which is shown in Table 3.

	Distance	GraspType	Supply	Tolerance	Symmetry	Force	Process Time
Type	numeric	selection	selection	selection	selection	numeric	numeric
Unit	cm	-	-	mm	-	Newton	seconds
decimal points	1	-	-	-	-	1	2
required/ optional	optional	optional	optional	optional	optional	optional	optional

Table 3: MTMmotion® data – influencing factors of the arm motions

Distance is the actual motion path taken, which is generally arched and measured in centimetres. For hand motions the base knuckle of the index finger is used as a measuring point to determine the distance. For finger motions the fingertip is used as a measuring point. The *GraspType* describes the posture of the hand when gaining or relinquishing control over an object. *Supply* refers to the arrangement or position of the object before it gets grasped. The *Supply* types differ in the way an object is provided: fixed location (e.g., a button), varying location each work process (e.g., tools) or jumbled with other objects of the same kind (e.g., screws).

Tolerance describes the maximum ± deviation from the Point of Initial Engagement and is used to specify the required place accuracy. There is a selection of five different tolerance ranges given which are specified in millimetres. *Symmetry* refers to the symmetry condition of the positioning process. There are two options of symmetry given to the user: either the object does not need orientation for the positioning process (e.g.: placing a nail on a wooden board) or it does need orientation (e.g.: placing a screwdriver on a screw).

Force describes the required force to move or position an object. It stands for the physical force exerted by the body and effects the object that needs to be moved or positioned. It is measured in Newton and can be entered by the user. *ProcessTime* is the time of a specific process that can be calculated through estimation, time study or by using self-activated recording instruments (e.g., time recorder).

It can represent the operating time of a tool or machine, for example, the screw process of an automated screwdriver or the press time of a press. *ProcessTime* is measured in seconds and is also an optional influencing factor.

6. Translation into MTM-UAS® analyses

The translation of the interface data into valid MTM analyses is the second part of the approach. This process is divided into the following process steps, which will be described in detail in the following sub-chapters:

1. Input data validation
2. Input data completion
3. Translation into process building blocks
4. Combination of different body parts

6.1. Input data validation

Firstly, the algorithm validates the input data supplied by the virtual reality tool. It checks whether the input data is meaningful or if it contains logical flaws. This means for instance that it checks if the handling of objects follows a meaningful order. Figure 5 shows a part of the validation algorithm. Here, the algorithm would detect an error if objects were moved that were not obtained before. In those cases, the object section, which includes all motions done with the same object in a sequential order, is deleted.

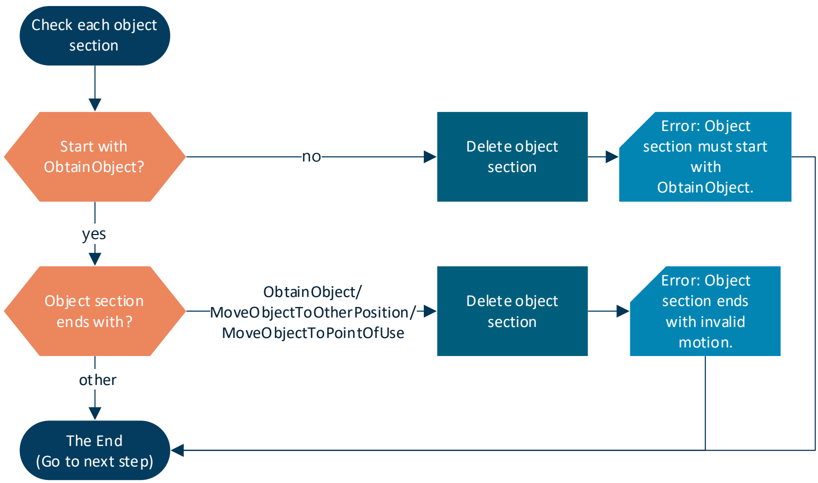

Figure 5: validation of object sections

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Additionally, the algorithm checks if the handling of an object ends with an invalid motion such as *ObtainObject* or *MoveObjectToPointOfUse*. Those motions are only a part of a meaningful object handling if they are followed by other motions like *UseObject*. In case the following motions are missing, the object section is deleted, and an error is issued. The given exemplary workplace can be used to explain this in detail (view Table 4). If the arm motion *ObtainObject* is missing for the screw (row 4, objectID 1), the meaning of the complete object section (rows 5-6) is unclear and thus deleted and not further used for translation.

time start	time end	object ID	side	arm motion
51.0	51.5	2	right	ObtainObject
51.5	52.5	2	right	MoveObjectTo OtherPosition
52.5	56.8	2	right	HoldObject
53.6	54.4	1	left	MoveObjectTo PointOfUse
54.4	56.8	1	left	UseObject

Table 4: missing arm motion for screw (objectID 1)

There are other queries the algorithm uses to check if the data provided by the user is conclusive. This article, however, does not aim to explain the whole algorithm, but focuses on a few examples to show how the translation works in general.

6.2. Input data completion

In the next step, the algorithm checks whether the input data is complete (view Figure 6). Although the interface contains all the information that is needed for a complete MTM analyses, it is not necessary to put in every non-essential information. First, the algorithm checks whether the used object exists in the provided object list. If that's not the case, a standard object replaces the unknown object, and an error is issued. The system cannot process an object that it is not familiar with. Then, missing information is filled with standard data. For example, the algorithm would add an average screw weight if it wasn't given by the VR tool. This step does not only apply for object data but also for all the motions and postures in the interface. For example, for all arm and leg motions except *UseObject* the standard value for distance is 40 centimetres. The Standard distance for *UseObject* is filled for each *UsageType* individually.

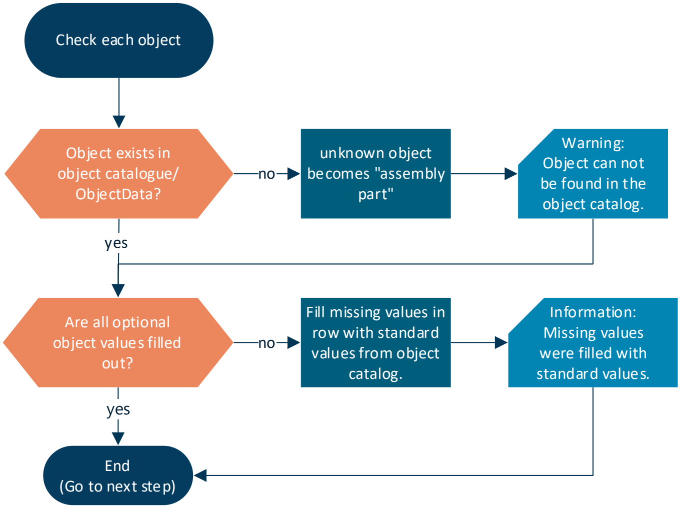

Figure 6: validation of object information

6.3. Translation into building blocks

One very important step of the algorithm is the translation of the various motions into MTM process building blocks. In the case of MTM-UAS®, it is often necessary to combine certain motions to basic operations (see Figure 1). However, each one of those combined motions supplies relevant data that is used to determine the right MTM-UAS® code.

object ID	side	arm motion	Basic Operation	CaseOfGet	CaseOfPlace
2	right	ObtainObject	Handle Tool	> 1 kg to < 8 kg	-
2	right	MoveObjectTo OtherPosition		-	approximately
2	right	HoldObject			
1	left	ObtainObject	Get and Place	≤ 1 kg, difficult	-
1	left	MoveObjectTo PointOfUse		-	loose
1	left	UseObject			
2	right	MoveObjectTo PointOfUse	Place	-	tight
2	right	UseObject		-	-

Table 5: translation of arm motions into interim result with basic operations

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That's why a first step in the translation into MTM-UAS® is the determination which motions are part of a basic operation. Table 5 shows the arm motions and their corresponding basic operations (column 4).

In the next step the influencing factors are deduced. For MTM-UAS® the *CaseOfGet* and the *CaseOfPlace* are central factors. The value *CaseOfGet* describes the way an object is obtained. This can vary from a simple obtain of a light object such as a screw to the difficult task of gaining control over a heavy box that weights 10 kg. These factors are calculated using the data of the object list as well as the arm motion data. For the exemplary workplace the influencing factors *CaseOfGet* and *CaseOfPlace* can be viewed in Table 5.

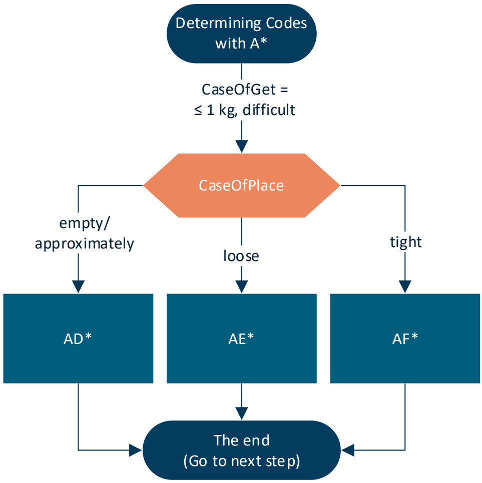

Figure 7: extract of the translation of Get and Place

Finally, the influencing factors are used to determine the correct code. A part of the algorithm to realize that step is shown in Figure 7. With the given influencing factors for the *Get and Place* of the screw (Table 4, rows 4-6; *CaseOfGet* ≤ 1 kg, difficult and *CaseOfPlace* is loose) the MTM-UAS® Code AE* is translated.

6.4. Combination of different body parts

The last step of the algorithm compares each Channel with motions with the other Channels to check if they influence each other or if there are motions performed at the same time. A very clear example for the influence of one channel on another is when a body motion is followed directly by an arm motion.

One of the MTM rules states that part of the arm motion can be performed during the body motion and thus the remaining effective distance of the arm motion is 10 cm. This rule is checked and realized in the MTMmotion® algorithm.

The MTM rules are also applied to check if motions 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 like the screwdriver. In that case, this does not result in a conflict. In contrast, if the worker would insert and screw in two screws simultaneously with each hand, the algorithm would determine that this is not possible according to the MTM rules and correct the resulting analysis.

6.5. Resulting MTM-UAS® analysis

The result of these four steps is a valid MTM-UAS® analysis that matches the interface data supplied by the VR tool. Table 6 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. In this test case, the automatically generated analysis from the VR input data and the manual analysis were identical.

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**

Table 6: Automatically generated MTM-UAS® analysis

7. Translation into MTM-HWD® analyses

The MTMmotion® interface and algorithms can be used to translate the motion data into various MTM analyses that have different application areas. While MTM-UAS® is classically used in batch productions, MTM systems like MTM-HWD® should be used for productions that have shorter cycle times (e. g. mass production) (MTM-1 2019; MTM-UAS 2019).

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Using MTMmotion® to get valid MTM-HWD® analyses follows the same process steps as for MTM-UAS®. That means technology providers like LIVINGSOLIDS can use the interface in the same way.

Additionally, the translation algorithm also follows the same procedure (see chapter 0). The first two steps are identical to those of MTM-UAS®. That means the data is validated and checked in the same way. Steps three (see chapter 7.1) and four (see chapter 7.2) are adapted to MTM-HWD® to realize the system process building blocks and system specific rules.

7.1. Translation into basic actions

In contrast to MTM-UAS® the MTM-HWD® algorithm almost never combines the various motions into basic operations. It rather translates them into basic actions for the creation of a valid MTM-HWD® analysis (view Table 7). Obtaining the screw and placing it on the screwdriver (Table 7, row 4-6) are translated into the basic actions "Obtain" and "Deposit".

<table>
<tr><th>object ID</th><th>side</th><th>arm motion</th><th>Basic Action</th><th>GraspMotion</th><th>CaseOfDeposit</th></tr>
<tr><td>2</td><td>right</td><td>ObtainObject</td><td>Obtain</td><td>Grasp</td><td>-</td></tr>
<tr><td>2</td><td>right</td><td>MoveObjectTo OtherPosition</td><td>Deposit</td><td>-</td><td>approximately B</td></tr>
<tr><td>2</td><td>right</td><td>HoldObject</td><td>no translation</td><td>-</td><td>-</td></tr>
<tr><td>1</td><td>left</td><td>ObtainObject</td><td>Obtain</td><td>Separate</td><td>-</td></tr>
<tr><td>1</td><td>left</td><td>MoveObjectTo PointOfUse</td><td rowspan="2">Deposit</td><td rowspan="2">-</td><td rowspan="2">close</td></tr>
<tr><td>1</td><td>left</td><td>UseObject</td></tr>
<tr><td>2</td><td>right</td><td>MoveObjectTo PointOfUse</td><td>Deposit</td><td>-</td><td>loose</td></tr>
<tr><td>2</td><td>right</td><td>UseObject</td><td>Hold</td><td>-</td><td>-</td></tr>
</table>

Table 7: translation of arm motions into interim result with basic actions

Since MTM-HWD® is a more detailed process building block system than MTM-UAS®, more influencing factors are processed in the algorithm. Most of them (e.g.: *TypeOfGrasp*) are read from the interface data and translated directly. Only a few are used subsequently to determine specific MTM-HWD® influencing factors, such as *GraspMotion* or *CaseOfDeposit*.

GraspMotion for example is the equivalent to *CaseOfGet* in the MTM-UAS® algorithm. It describes the way the hand or fingers gain control over an object before further moving it. *GraspMotion* is calculated using the object data as well as the values *TypeOfGrasp* and *Supply* which were provided for the arm motion.

7.2. Combination of different body parts

The rules to combine different body parts in MTM-HWD® are like those that are used for MTM-UAS®. As explained in chapter 6.4, the algorithm compares each Channel with motions with all other motion channels and checks if they influence one another. For example, the MTM rule for the remaining effective distance for an arm motion after a body motion is displayed in Figure 8.

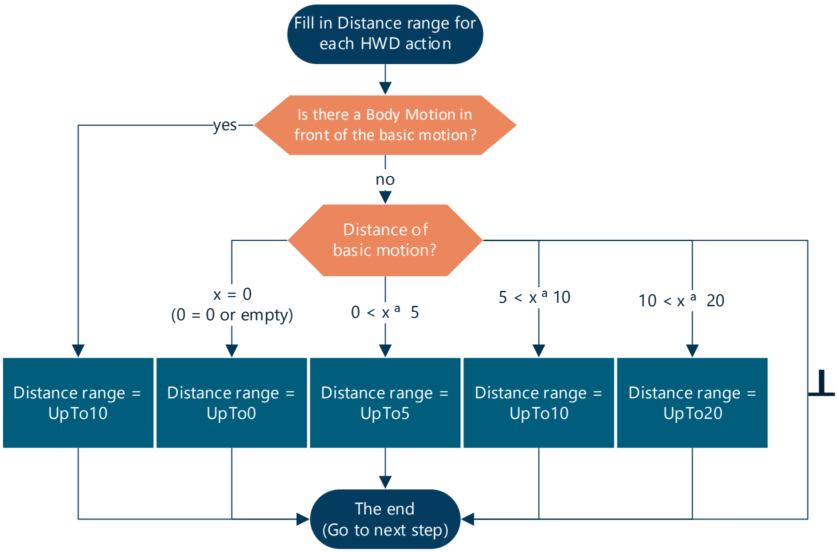

Figure 8: Determination of distance range by considering body motions

To determine the actual distance for an MTM-HWD® action, the algorithm checks every basic motion (origin in Channel 2 or 3) for the occurrence of a body motion (Channel 1) right in front of it. If this case occurs, the distance range for the MTM-HWD® action is set to UpTo10 (equals up to 10 cm). Otherwise, the distance of the basic motion is used to determine the distance range for every MTM-HWD® action as shown in Figure 8.

7.3. Resulting MTM-HWD® analysis

All these steps lead to an MTM-HWD® analysis that is consistent with the MTM-UAS® analysis. The screwdriver is taken into the work area, the first screw is placed onto the screwdriver and then screwed in with the screwdriver. This last part is repeated for the second screw. This process can be seen in the MTM-HWD® analysis in Figure 9 in column "Description". In addition, the analysis can be understood by looking at the pictograms. For example, the column "general settings" describes the object, what kind of HWD action is performed and which hand is handling the object. The second row refers to the screwdriver that is obtained with the right hand. Furthermore, the weight of the object and additional forces are shown for the MTM-HWD® analysis.

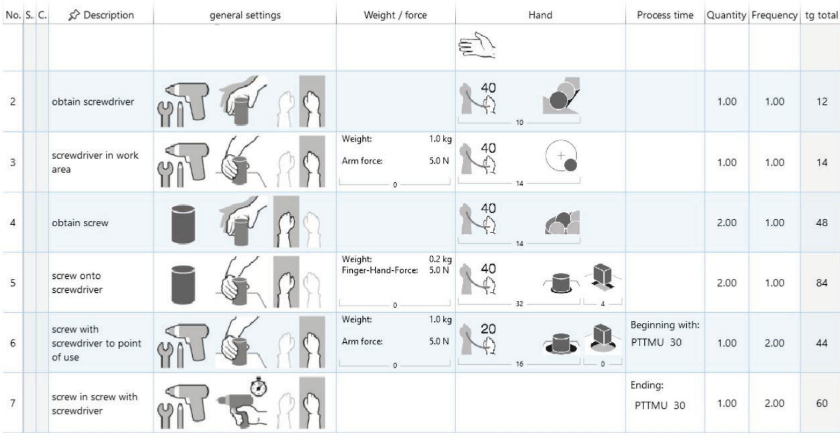

Figure 9: MTM-HWD® analysis

The influencing factors for the hand are listed in column "Hand". Row 5 shows the place motion of the screw onto the screwdriver. This process covers a distance range of 40 cm with a close fit of the screw while orienting it before placing it onto the screwdriver. The process time of the screwdriver can be viewed in row 6, column "Process time".

Other important values are "Quantity" and "Frequency". Due to the repetition of placing a second screw onto the screwdriver and screwing it in, the quantity in row 4 and 5 is set to 2 and the frequency in row 6 and 7 is also set to 2. There are additional influencing factors (e.g., upper body, trunk, or arm postures) that are not included in Figure 9, because explaining all of them is beyond the scope of this publication.

The result of this MTM-HWD® analysis has a total standard time of 262 TMU (approx. 9.5 seconds).

8. Conclusion and Outlook

8.1. Critical Discussion

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

1. Completeness of VR data:

   Since the process relies on the transferred data from the VR tool into the data interface, two aspects must be considered. Firstly, it is necessary that the VR tool can model the necessary data in a VR simulation. Secondly, it is important that the data is input correctly by the VR user. A good example for this 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. However, the quality in a wide use must be checked in future cases.

3. Translation of motion data "as provided":

   The approach only focuses on the work process that was modelled in the VR tool. That means that exactly this motion data is translated without checking if it would make sense for the real product in a real production. If the process is modelled incorrectly or unnecessarily complicated, the resulting MTM analysis describes exactly that process. Therefore, it will still be necessary to involve an industrial engineer to check the modelled process and the translated MTM analysis.

When those aspects are properly handled, the approach can help industrial engineers to plan workplaces in a modern and efficient way. If VR technologies are already used in their company, 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.

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8.2. Outlook

To improve the approach and thus its usability, several development steps will be carried out. Firstly, the number of industrial use cases will be expanded to test the approach with several additional workplaces. Secondly, other VR tools will be enabled to supply the interface data. Thirdly, other MTM process building block systems such as MTM-1® will be implemented. These steps aim to advance the combined use of VR and MTM in industrial companies.

Because the interface data was built so that it can be accessed by any technology that records or generates motion data, it is possible to transfer the approach to technologies such as human simulation tools like the ema Work designer (imk 2023) or motion capture suits like the Xsens suit (Movella 2023). The transfer of this approach 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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