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Integrating Physical Load Exposure Calculations and Recommendations in Digitalized Ergonomics Assessment Processes

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Abstract. The type of ergonomics assessment methods typically used in digital human modelling (DHM) tools and automated assessment processes were rather developed to be used by ergonomists to assess ergonomics by observing the characteristics of the work. Direct measurement methods complement observation methods. Direct measurement methods have a design that suits being implemented into DHM tools. A drawback of direct measurement methods is that they traditionally do not include action levels. However, action levels in direct measurement methods have recently been suggested. The aim of this paper is to illustrate how these recent physical load exposure calculations and recommendations can be integrated in a DHM tool and in an automated assessment process. A demonstrator solution was developed that inputs exposure data from simulations in the DHM tool IPS IMMA as well as exposure data that originate from tracking real workers' motions, using the motion capture system Xsens MVN. The demonstrator was applied in two use cases: one based on predicted human motions and one based on captured human motions. In the demonstrator, head posture, upper left and right arm posture and velocity, as well as left and right wrist velocity were calculated. Exposure data were compared with action levels, and extreme action levels were indicated by colouring the information. The results are promising, and the demonstrator illustrates that it is possible to follow the trends in Industry 4.0 and Industry 5.0 to automate and digitalize ergonomics assessment processes in industry.

Keywords. Action levels, digital human modelling, motion capture, ergonomics assessments

1. Introduction

Simulation and automation are elements in the Industry 4.0 transformation that effect manufacturing industry production systems and way of working [1]. Recently the concept Industry 5.0 has been introduced, reinforcing the human-centric perspective of Industry 4.0 [2]. Digital human modelling (DHM) tools are a human-centric category of simulation software that facilitates proactive consideration of ergonomics in computer-

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generated environments, hence requiring no physical prototypes [3]. DHM software can, for example, be used at early stages of the design process to build, visualize, assess, optimize, and verify workplace designs. For the approach in which ergonomics assessments are rather made on physical prototypes or in running operation, tools such as smart textiles [4, 5], motion capture systems [6], and other types of sensor-based equipment, e.g. [7, 8], have been introduced in industry to automate the assessment of ergonomics, with the purpose of enhancing efficiency and objectivity compared with traditional approaches of how to assess ergonomics.

However, the physical load assessment methods typically implemented in DHM tools and in automated assessment processes are not really adapted to be used in these types of digitalized applications. The type of assessment methods typically used in DHM tools and automated assessment processes were rather developed to be used by ergonomists to assess ergonomics by observing the characteristics of the work. Examples of such observation methods are OWAS (Ovako Working Posture Assessment System) [9], RULA (Rapid Upper Limb Assessment) [10], and REBA (Rapid Entire Body Assessment) [11]. Several observation methods exist and none of the methods is superior to another [12]. The methods normally include action levels, which are recommendations of how to act based on the outcome of the method, e.g., *no action needed*, *changes in near future required*, or *changes need to be made at once*. Not following the recommendations given by the methods leads to the risk that workers will suffer from musculoskeletal disorders in the future. These observation methods were not made for analyses based on large continuous time-stamped data sets. An alternative to observation methods is direct measurement methods. Several direct measurement methods and a few other methods that consider time aspects for assessing physical loads exist [13]. Such methods allow analyses of continuous streams of data. Hence, they represent a type of methods that are better suited to being implemented into DHM tools and automated assessment processes, compared with observation methods. A drawback of the direct measurement methods is that they traditionally do not include action levels, meaning that they are not really useful to others than ergonomics experts. However, action levels in direct measurement methods have recently been suggested by researchers in the area of ergonomics [14]. Arvidsson et al. propose action levels for movement velocity (upper arm and wrist), posture (head and upper arm), and muscular load (trapezius and forearm extensor).

The aim of this paper is to illustrate how these recent physical load exposure calculations and recommendations are integrated in a DHM tool and in an automated assessment process.

2. Method

The DHM tool IPS IMMA [15] was used as a demonstration platform (Figure 1). The workflow (Figure 2) in the DHM tool was: 1) define and create the manikin, 2) define and build the environment, tools, and parts, 3) define the task to be performed, 4) run the simulation, and 5) use the demonstrator solution to perform ergonomics evaluation of the task performed by the manikin in the virtual environment. The movement velocity and posture exposure calculations and action levels from Arvidsson et al. [14] (Table 1) were used and programmed into the demonstrator software via LUA scripting, and calculations were made at a PHP (Hypertext Preprocessor) server. The visualization was also done at the server. This demonstrator does not include the muscular load exposures in [14]. The observation method OWAS [9] and the cumulative OWAS score, known as the Lundqvist index [16], were used to compare results from the direct measurement method. The Lundqvist index considers the percentage of time in each of the four action categories of OWAS, resulting in a value from 100 to 400, where 100 is best (100% of time in "green") and 400 worst (100% of time in "red") in regard to risks for work-related musculoskeletal disorders (WMSDs). The assessment scores were visualized in a graphical interface. A simulation of a pedal car assembly task was used as demonstration case.

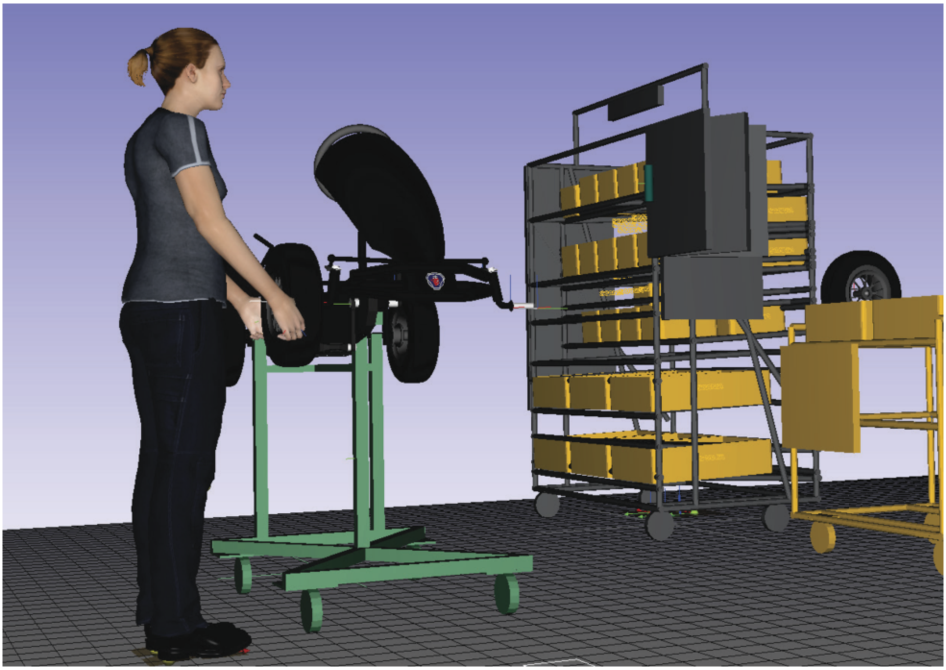

Figure 1. Simulation of placing right front wheel of the pedal car, one of the tasks at Station 3 on the pedal car line used for demonstration.

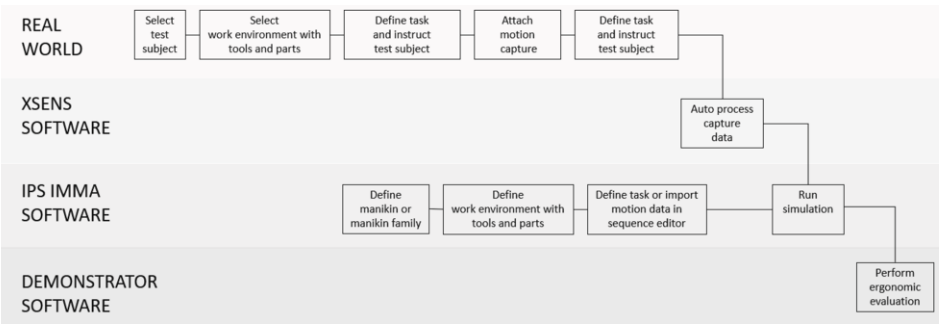

Figure 2. The workflow in the DHM tool (swim lanes: IPS IMMA software and Demonstrator software), and in an automated assessment process (swim lanes: Real world, Xsens software, IPS IMMA software, and demonstrator software).

The IPS IMMA software [15] in combination with the Xsens MVN Analyze (software) and Awinda (hardware) motion capture systems [17] was used to illustrate the implementation of direct measurement methods in an automated assessment process, i.e., used to measure the exposure of physical load to a real person in a physical factory. One subject working in a station in truck manufacturing was used as demonstration case. The workflow (Figure 2) in the automated assessment process was: 1) select test subject, 2) select work environment with tools and parts, 3) define task and instruct test subject, 4) dress test subject with motion capture system; test subject performs the task, 5) auto process captured motion data, 6) import the motion capture data in the IPS IMMA sequence editor, 7) run the simulation, and 8) use the demonstrator solution to perform ergonomics evaluation of the task performed by the worker in the real environment.

Table 1. Exposure measures and action levels for physical workload concerning movement velocities and postures from Arvidsson et al. [14] integrated in the IPS IMMA demonstrator

	Action level		
	10^{th} percentile	50^{th} percentile	90^{th} percentile
Movement velocity			
Upper arm		60°/s	
Wrist		20°/s	
Posture			
Head extension/flexion	-10°	< 0° or > 25°	50°
Elevated upper arm		30°	60°

3. Result

The results demonstrate an integrated solution where the exposures relate to head posture, upper left and right arm posture and velocity, as well as left and right wrist velocity. Exposure data were compared with action levels. A user interface was created, and the exposure values were visualized (Table 2). Extreme action levels were indicated by colour. A full red square indicates that the action level is exceeded on the actual hierarchy level. A half-filled red square indicates that the action level is exceeded on a lower level in the hierarchy. Hence, if a half-filled square is present at line level in the hierarchy, the action level has been exceeded on station, task, family, or manikin level.

As can be seen in Table 3, the exposure scores with exceeded action levels from Arvidsson et al. [14] correspond well to the risk levels indicated by the Lundqvist index [16]. Simulation of Station 1 indicated that action levels were exceeded for both left arm angular 50^{th} percentile as well as left and right arm angular 90^{th} percentile. Correspondingly, Station 1 also had the highest Lundqvist index score, both average and maximum score. Simulation of Station 2 showed that action level was exceeded for right arm 50^{th} percentile, and Station 2 also had the second highest Lundqvist index, both average and maximum score. Simulations of Station 3 and Station 4 revealed that action levels were not exceeded, neither for Arvidsson et al. nor the Lundqvist index, considering exposures on station level. This indicates that all movements in Stations 3 and 4 were performed within a zone that in the long run should not be harmful to the operators.

Table 2. Movement (wrist and arm velocity) and posture (head angle) exposure of a female manikin on line, station, and task level. A full red square indicates that the action level is exceeded on the current level. A half-filled square indicates that the action level is exceeded on a lower level in the hierarchy

	Left Wrist Velocity p50	Right Wrist Velocity p50	Left Arm Angular p50	Left Arm Angular p90	Left Arm Velocity p50	Right Arm Angular p50	Right Arm Angular p90	Right Arm Velocity p50	Head Angular p10	Head Angular p50	Head Angular p90
Scene	1.7	4.0	23	51	4.3	24	50	6.6	-7.2	-6.3	-5.6
Factory 3	1.7	4.0	23	51	4.3	24	50	6.6	-7.2	-6.3	-5.6
PedalCar Line	1.7	4.0	23	51	4.3	24	50	6.6	-7.2	-6.3	-5.6
Station 1	0.57	5.2	35	62	4.7	24	64	7.2	-7.3	-6.2	-4.0
Station 2	0.57	3.4	16	42	3.9	33	51	14	-7.2	-6.2	-5.6
Station 3	3.4	4.0	25	53	3.8	20	47	4.5	-7.3	-6.4	-6.0
46 Fetch LFwheel	3.7	2.9	21	35	4.6	27	36	3.8	-6.4	-6.3	-6.1
47 Place LFwheel	11	11	17	17	2.4	18	24	6.4	-6.5	-6.4	-6.2
48 Fetch RFWheel	3.2	6.0	20	37	5.1	17	34	5.8	-6.5	-6.4	-6.1
49L Place RFWheel	4.6	5.2	17	19	1.8	17	19	2.5	-6.5	-6.5	-6.4
52 Mount screw RF wheel	0.57	1.1	16	16	1.4	23	25	3.4	-6.1	-6.0	-5.7
55 Mount screw LF wheel	0.57	2.9	16	16	1.1	19	20	1.9	-6.1	-6.0	-5.9
56 Torque LFWheel	3.7	3.4	31	49	10	22	71	7.9	-7.3	-6.8	-6.2
Family 1	3.7	3.4	31	49	10	22	71	7.9	-7.3	-6.8	-6.2
Female_w=65_s=1674	3.7	3.4	31	49	10	22	71	7.9	-7.3	-6.8	-6.2
58 Torque RFWheel	6.6	6.0	36	70	5.4	31	59	3.9	-7.3	-6.9	-6.2
Station 4	4.0	1.7	21	36	4.3	18	39	4.1	-6.9	-6.4	-6.0

Table 3. Exposure scores calculated according to Arvidsson et al. [14] and the Lundqvist index [16]

	Left Wrist Velocity p50	Right Wrist Velocity p50	Left Arm Angular p50	Left Arm Angular p90	Left Arm Velocity p50	Right Arm Angular p50	Right Arm Angular p90	Right Arm Velocity p50	Head angle p10	Head angle p50	Head angle p90	Lundqvist index OWAS average	Lundqvist index OWAS max
Pedal car simulation in digital human modelling tool													
Line	1.7	4.0	23	51	4.3	24	50	6.6	-7.2	-6.3	-5.6	128	390
Station 1	0.57	5.2	35	62	4.7	24	64	7.2	-7.3	-6.2	-4.0	157	390
Station 2	0.57	3.4	17	42	3.9	33	51	14	-7.2	-6.2	-5.6	146	269
Station 3	3.4	4.0	25	53	3.8	20	47	4.5	-7.3	-6.4	-6.0	100	100
Station 4	4.0	1.7	21	36	4.3	18	39	4.1	-6.9	-6.4	-6.0	100	100
Motion capture recording in real environment													
Station	20	18	12	27	10	11	26	8.6	12	28	37	116	116

Both assessment methods, Arvidsson et al. and the Lundqvist index, indicated low risk for the station analysed by the automated assessment process in the physical truck manufacturing (Table 2). The recommended action levels in Arvidsson et al. were not exceeded, and the Lundqvist index score indicates that most of the movements are performed using postures with no or low risks for WMSDs.

4. Discussion

The results are promising, and the demonstrator illustrates that it is possible to utilize the fact that both the DHM tool and the automated posture assessment process, using motion capture combined with a DHM tool, generate data in a similar fashion to direct measurement technology and show that the recently suggested action levels can be related to. The recently published action levels proposed by Arvidsson et al. seem to correspond well to risk levels given by the Lundqvist index, a time-based version of the established observation method OWAS. OWAS is available in several DHM tools as a method to assess working postures. The demonstrator, illustrating that it is possible to use Arvidsson et al.'s exposure calculations and action levels as well as the Lundqvist index, is a development step in the direction recommended by Berlin and Kajaks [13]. It is also a step towards the visions and objectives of Industry 4.0 and Industry 5.0 [1, 2].

In total, the demonstrator covers three elements of the ongoing transformation towards Industry 4.0: simulation, big data, and automation. In the demonstrator presented in this paper, all these three elements concern human aspects related to the operators working at the manufacturing station, the person doing the ergonomics assessment of the workstation, or the user of the DHM tool. The simulation tool used in the demonstrator, i.e., the DHM tool IPS IMMA, supports engineers, designers, and ergonomists to find workstation design solutions that optimize human well-being and system performance, for the benefit of the operators as well as for the end user of the product or production system. The big data consist of physical load exposure data of the operators. The data are generated in the DHM tool or captured with a motion capture system in the physical world, providing much more data than attainable when using observation-based methods in a traditional manner. However, it is far from millions of data samples per hour that most people refer to when talking about big data. Still, it is one step forward in handling big data sets in an objective way. Automation was in focus to facilitate functionality and usability for the user of the DHM tool. The exposure data are automatically analysed in the DHM tool, regardless of whether the origin of the data lies in simulations or in recordings in the real world. The data analysis in the demonstrator is fully automated, which provides objective results. This is a step in the right direction, since there is a call for more objective ergonomics assessment methods. Previous studies, e.g. [18], have shown that there is a need of new ergonomics assessment methods and processes to increase both inter- and intra-observer reliability, something that has not been satisfactory with methods relying only on manual judgment and observation.

The demonstrator gives priority to human aspects and is a good example of the visions and objectives of Industry 5.0. The demonstrator also illustrates that it is possible to use the same tool and assessment method in the virtual world and in the physical world, reducing the gap in ways of working between early design phases and later operation phases. Even if this early demonstrator is promising, more research, integration, and usability work needs to be carried out.

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