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Simulation of Ergonomic Assembly Through a Digital Human Modeling Software

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Abstract. Musculoskeletal disorders (MSD) as a result of bad workplace design and ergonomics are one of the leading causes of work-related injuries, this is especially true for assembly workers within the manufacturing industry.

This paper investigates the possibilities to implement an automated ergonomics evaluation assessment into a Digital Human Modeling (DHM) software to evaluate workplace design for assembly tasks within manufacturing. A benchmarking and screening process was conducted to identify the most suitable ergonomics assessment method to be implemented into the DHM software. Furthermore, a pilot implementation, using Industrial Path Solution (IPS) Intelligently Moving Manikin (IMMA) as the referenced DHM software, was held with China Euro Vehicle Technology (CEVT) to solidify the results of the integrated function. This paper showcases that automated ergonomics assessment methods can, successfully, be integrated into a DHM software.

Keywords: Digital Human Modeling · Ergonomics · Software · Simulations · Virtual Verification

1 Introduction

Every year, millions of people report taking time off from work to recover from MSDs, ultimately costing the society hundreds of billions of dollars annually [1–3]. MSD causes many humans to feel pain in their muscles and joints, which limits their ability to move and withstand loads for a longer period of time [4]. These factors can be the direct consequence of bad ergonomics at a workplace, and could result in serious injuries if not treated properly [5]. Moreover, bad ergonomics has shown to also have a huge impact on production quality. Studies report that on average 80% of tasks with medium or high ergonomic loads in automotive production results in quality problems [6, 7]. Therefore, making assembly operations ergonomically sound is crucial in order to ensure sustainable workplace design, quality and productivity [8].

This paper aims at investigating the possibilities of automating a full ergonomics assessment method into a DHM software.

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1.1 Digital Human Modelling

DHM software is a tool for simulating, analysing and evaluating human movement and interactions with products and processes in a digital environment. By working with a family of virtual human manikins representing anthropometric data of a particular demographic, and exposing these to objects and tasks, parameters such as reachability, accessibility and ergonomics can be assessed [4]. However, full ergonomics assessments in a virtual system are rarely performed due to its higher complexity and the greater need of data such as force estimates, time estimates, production layout, production leveling etc. Data that as of today is seldom simulated or available in any DHM software.

The DHM software IPS IMMA is a product of collaborative research performed by Swedish industry and universities. The software combines ergonomics analysis capabilities with path planning solutions [9]. Using a kinematic model composing of 82 bones and 162 joints, the manikin inherits a rigid and skeleton-like structure capable of mimicking the human body and taking on any anthropometric shape and form [10].

IPS IMMA introduces intelligent path planning and movements of its manikins as IMMA relies on algorithms to predict the most human like postures [9]. Taking equilibrium, balance and comfort of each body joint and body part into consideration it is able to predict human-like movements [11].

1.2 Ergonomics Assessments

There is a number of factors that interplay in the human body's ability to exert physical loads in a harmless way. Posture, force and time are the three most important factors to consider. The interaction between these factors will determine the risk and severity of potential injuries (e.g. MSD) connected to a specific physical load situation [4]. It is therefore crucial to assess these factors individually, in order to assess the total physical load situation and possible harm inflicted on the human body. This can be done using ergonomics assessment methods [4].

As of today, there are many standards and methods used by the industry, most of which examines and grades the posture of an operator. This is often done by measuring angles and distances of particular body parts of interest [4]. Furthermore, more complex methods additionally considers forces and torques exerted on the human body over time in order to assess the total harm. In addition, environmental and organisational factors could potentially also be assessed and taken into consideration by methods that strives towards a more comprehensive representation of the physical loading effect [4].

2 Methodology

The methodology used by the authors to investigate the feasibility of implementing a fully automatic ergonomics assessment into a DHM software composes of the three following steps; Finding a suitable ergonomics method for implementation, integrating the chosen method into a DHM software and validating the results through an industry case study.

2.1 Ergonomics Assessment Method Selection

Candidates of ergonomics assessment method for implementation were selected based on literature provided by Berlin and Adams [4] and their use within manufacturing industries, making them credible and relevant for the study.

The ergonomics assessment methods were screened against each other through a qualitative study of the literature and instructions associated with each method. Time, force, postural and external factors taken into consideration by each ergonomics assessment method was recorded to give an overview of which method covers which aspects of ergonomics and to what extent, pinpointing clear discrepancy and characteristics of each method. Furthermore, using the selected DHM software as a reference, and by cross-linking the criteria of each ergonomics assessment method with the simulation data available, it could be illustrated to what extent each method could potentially be automated by the DHM software.

The four methods that had the highest correlation between the factors and measurements covered by the method and the availability of data in the DHM software (i.e. top qualifiers) were chosen as contestants in a Kesselring decision matrix. The criteria used in the decision matrix and their corresponding weights were determined after gathering a detailed view of what the ergonomics evaluation method should focus on based on the injury statistics of MSDs for relevant industry [12] and interview studies with ergonomics experts from both the manufacturing industry [12–14] and academia [15]. Likewise, previously performed qualitative interviews and literature study composed the input on the rating of each assessment method. The Kesselring matrix resulted in one ergonomics assessment method selected for integration into the DHM software.

2.2 DHM Implementation

IPS IMMA was selected as the DHM software used for implementation in this research. Using the available API for IPS IMMA and a custom-built script using LUA programming language, the selected ergonomics assessment method was integrated into IPS to enable automatic ergonomics evaluations. The available API enabled for both simulation data and user input to be captured and used by the developed feature when calculating the ergonomics scoring according to the selected assessment method.

2.3 Industry Case Validation

The developed ergonomics evaluation feature in IPS IMMA was piloted in three case studies, together with CEVT, the projects pilot company. The case studies were selected to represent generic and commonly encountered assembly tasks performed in automotive final assembly. By replicating the assembly scenario of each case study within IPS IMMA the authors were able to compare the simulated ergonomics assessment results to the manual assessment executed by ergonomic experts at CEVT. The comparison and deviation in scoring would later be the basis for the future discussion to be held.

3 Results

In the following sections the results of the of the study are presented following the structure and methodology presented in previous section.

3.1 Ergonomics Assessment Method Evaluation

A total of 11 ergonomics assessment methods were chosen for evaluation. The selected ergonomics assessment methods and their complexity based on postural, time and force factors taken into consideration by each method, as well as its correlation to the available simulation data from the IPS IMMA software, can be seen in Fig. 1. From the results in Fig. 1 it can be seen that REBA, KIM III, RAMP and HARM hade the highest complexity in terms of number of relevant factors, take into consideration by each assessment method, as well as the highest correlation of available simulation data in the referenced IPS IMMA software. These four methods were therefore selected for a final screening using a Kesselring decision matrix.

Benchmarking of Evaluation Methods		Ergonomic evaluation methods											
		REBA	RULA	OWAS	EAWS	NIOSH	KIM I	KIM II	KIM III	HARM	RAMP	JSI	IPS
Neck:	Flexion/Extension	x	x						x	x	x		x
	Lateral bending	x	x						x	x	x		x
	Forward head posture									x			
	Twist	x	x						x	x	x		x
Trunk:	Flexion/Extension	x	x	x	x		x	x	x		x		x
	Lateral bending	x	x	x	x			x	x		x		x
	Twist	x	x	x	x	x	x	x	x		x		x
	Support				x								
Legs:	Flexion/Extension	x		x	x		x	x					x
	Lifting	x	x	x									
	Weight distribution								x		x		x
	Sitting			x	x				x				
	Squatting				x		x	x					x
	Kneeling			x	x		x	x					x
	Suppport				x				x				
	Walking/Standing			x	x				x				
Upper arm:	Flexion/Extension	x	x	x	x		x		x	x	x		x
	Abduction/Adduction	x	x		x				x	x	x		x
	Raised shoulder	x	x							x			x
	Support	x	x		x					x			
Lower arm:	Extension/Flexion	x	x		x				x	x	x		x
	Crossed arms		x										x
	Support								x				
	Internal/External rotation		x				x		x		x		x
Wrist:	Flexion/Extension	x	x		x				x	x	x	x	x
	Radial/Ulnar deviation	x	x		x				x	x	x	x	x
	Supination/Pronation	x	x		x				x	x			x
Hands:	Grip	x			x	x			x	x	x		
	Finger forces				x				x	x			
Time:	Repetativeness	x	x		x	x	x	x	x	x	x	x	
	Exposure time				x	x	x	x	x	x	x	x	
	Rapid motions	x						x			x	x	
Force/Load:	Weight	x	x	x	x	x	x	x		x	x		
	Distance				x	x	x	x					
External factors:	Environmental				x		x	x	x	x	x		
	Organizational				x		x	x	x	x	x		

Fig. 1. Comparison matrix from the benchmarking study including the selected ergonomics methods and the available measurements of the IPS IMMA software.

The Kesselring matrix, which can be seen in Fig. 2, showcases that KIM III was the most suitable method for an implementation into IPS IMMA as it covered postures of the most risk-prone areas of the body related to assembly work within the manufacturing industry, as well as took into consideration crucial time and force aspects. In addition, the KIM III input data and measurements have a clear correlation of the simulation data available and retrievable in IPS IMMA, which makes a potential successful implementation more likely.

Decision Matrix		Ergonomic Evaluation Method							
		REBA		KIM III		RAMP (I & II)		HARM	
Criteria	Weight	Rating	Total	Rating	Total	Rating	Total	Rating	Total
Neck	3	3	9	4	12	4	12	4	12
Trunk	3	3	9	4	12	4	12	0	0
Legs	2	4	8	2	4	2	4	0	0
Upper arm	4	3	12	4	16	3	12	4	16
Lower arm	4	2	8	4	16	1	4	4	16
Wrist	5	3	15	4	20	3	15	4	20
Hands	5	2	10	2	10	4	20	3	15
Forces	4	2	8	4	16	4	16	3	12
Time	4	2	8	4	16	5	20	5	20
External factors	2	0	0	3	6	5	10	4	8
Clear scoring	3	4	12	5	15	4	12	5	15
IPS availability	4	4	16	3	12	3	12	3	12
	Total score:		115		155		149		146

Fig. 2. Kesselring decision matrix.

3.2 DHM Integration

The KIM III ergonomics assessment method was implemented as a feature to the IPS IMMA software. Firstly, the feature poses a number of pop-up questions to the user regarding force, time and external factors – which as of now are difficult to simulate with current DHM software. Secondly, simulation data concerning postural factors of the manikin is captured by the IPS software. The results of the evaluation are thereafter automatically displayed to the user in the form of a complete KIM III assessment report.

The developed functionality in IPS creates a matrix, recording the rotation in X, Y and Z of 19 selected joints of a family of manikins used in the simulation. The 19 joints used in the evaluation have been selected in regard to the postural aspects of KIM III as well to create a holistic representation of the manikin's full body posture, see Fig. 3 for a visualization of the selected joints. The 12 joints in the figure are in practice 19, as some of the joints visualized in the figure are duplicated on both sides (left and right) of the manikin.

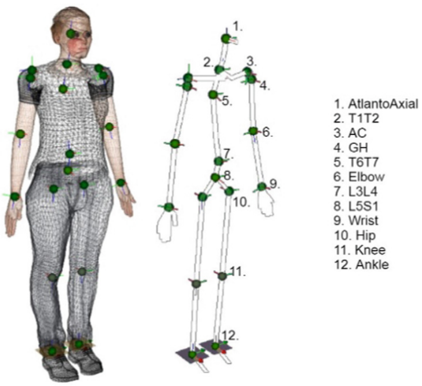

Fig. 3. A visualization of the joints positions and formulations considered by the script.

Once the simulation data is captured, it is graded according to the guidelines developed by the German federal institute for occupational safety and health (BAuA), the founders of KIM III [16]. An example of one of the KIM III postural grading conditions and its corresponding IMMA joint is illustrated in Fig. 4.

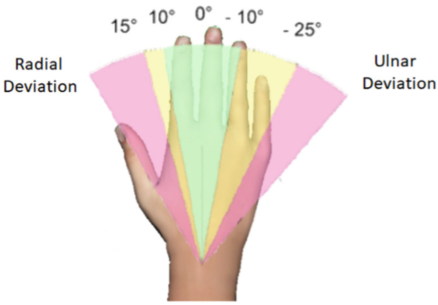

Fig. 4. An example of a KIM III grading constraint on the right wrist.

The grading and scoring of each joint angle in combination with the input of the additional questions posed to the user, enables IPS IMMA to automatically calculate and visualize the results of the ergonomics assessment according to the KIM III report template.

3.3 Industrial Case

The results of the completed cases studies showed that the digital assessment correlated well with the physical assessment performed by CEVT's ergonomics expert, see Fig. 5. Although some slight deviation in final score was attained in all three cases, however, they all ended up within the same risk range according to KIM III – thus achieving alike outcome. It was concluded that the small deviation in final score of the digital implemented KIM III derived from slight posture differences of the hands and arms of the manikin. Taking the ergonomist's manual assessment as reference, this could either imply that the function needs to be further validated, that there have been deviations in the input data or that there is discrepancy between the observational assumptions made by the ergonomist and the actual simulated joint angles of the manikins.

	Manual KIM III	Digital KIM III
Case 1	90 Unacceptable	81 Unacceptable
Case 2	36 Review	30 Review
Case 3	10,5 Acceptable	8,5 Good

Fig. 5. Table of KIM III final assessment scores for the three cases achieved by the CEVT ergonomists (to the left) and the digital function (to the right).

4 Discussion

Based on the analyses made throughout the industrial case, it can be seen that when comparing the digital and manual assessments, the posture score can vary – without having a significant impact on the final score. This is especially true for hand and arm postures, body parts which have previously been documented to be difficult to simulate using DHM software [15]. Hence, by solely looking at the final score of an assessment, a task could still be approved with an existing ergonomic risk for the operators' arms or hands. The authors have thereby identified some potential areas of future research.

Being able to anticipate and simulate the correct motions and postures is vital in order to achieve an accurate and representative ergonomics assessment. There are often multiple different ways of how to perform a task and consequentially just as many different postures that could be adapted. Hence, one of the biggest challenges a user of any DHM software has, is to anticipate the correct posture that would represent the reality of the situation [13]. To do so, it is important to define the term "correct posture", as there are always going to be deviations in how operators perform certain tasks. Two possible areas of future work that would address this issue and assist in anticipating and simulate the correct posture were identified.

(1) The IPS IMMA software with its path planning capabilities and intelligent kinematics model is one of the more advanced manikins available to date when it comes to anticipating postures and movements according to assigned tasks [9]. However, the results of this project show that even more research might be suggested regarding path planning functionality and manikin movements, especially for DHM software currently lacking this functionality. A conclusion drawn as the analyses of the industry case illustrated postural deviations in all three cases.
(2) The second proposed area of future research that could help in achieving accurate motions and postures of a DHM manikin, is the use of Virtual Reality (VR) and motion capture systems. VR allows the DHM users to perform assembly tasks in a virtual environment, creating a better feeling of how the task could be performed in a realistic way [17]. In combination with a motion capture system, the motions performed in the VR simulation could be captured and transferred into the DHM software bringing realistic motions to its manikins [18].

Further work should also include investigation of which ergonomics assessment methods or standards would be most suitable to implement into DHM software. Are there any methods that seemingly would be a better fit to implement than the KIM III method implemented in this project? Or would it be beneficial to implement solely postural judgements? Moreover, most ergonomics assessments methods, currently available, were developed before ergonomics simulations and DHM software were established and relies therefore on physical observations from a third part. One could therefore argue that these methods would not translate well to a DHM software. Therefore, the development of an ergonomics assessment method designed for simulation purposes would be of great interest as future research.

Lastly, until DHM software are capable of reliably simulating time, force, environmental and other external factors, manufacturers need to attain this data elsewhere and make it available for the users of the DHM software in order to provide reliable input to the ergonomics assessment. This could for instance be achieved and simulated using various digital twins [19]. If this data can't be attained and presented to the DHM simulation engineer, one might suggest that it would be better to consider solely postural assessments for an DHM ergonomics evaluation – at least until such data can be properly simulated or presented.

5 Conclusion

From the analysis in this paper, the conclusion could be drawn that the implemented function correlated well with the manual ergonomics assessments made by the ergonomist at CEVT. The pilot implementation showcases thereby that an ergonomics assessment could be automated digitally with the use of IPS IMMA, saving valuable time spent on making manual assessments. Moreover, the application could eventually improve anthropocentric ergonomics, leverage performance and generate economic value in process development, product development and production technology. The following conclusions regarding the application may be drawn:

1. The tool can be used to make digital ergonomics assessments of the KIM III method through IPS IMMA.
2. The digital assessment can to some extent automate ergonomics evaluations but should at this point not fully replace physical evaluations.
3. The user needs to have some consisting knowledge in DHM, ergonomics and manufacturing in order to make a justified evaluation.
4. The evaluation is dependent on the manikin's posture, measuring its joint positions and rotations. It is therefore essential that the manikin represents the actual operation to make a truthful assessment.
5. KIM III, as well as all covered ergonomics assessment methods in this project, is observation based, meaning that a fully automated solution was difficult to achieve, and additional input is still needed by the user.

This paper has shown that full ergonomics assessments of manual assembly work can be automated using a DHM software. This can be achieved by implementing appropriate ergonomics assessment methods, acquiring the essential information and data needed to complete the assessment as well as setting up an accurate and representative scenario within the DHM software.

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