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The Need for Faster and More Consistent Digital Human Modeling Software Tools

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Abstract. The vehicle industry is a common user of Digital Human Modeling Software (DHMS) tools, both for product development and production process development. One of three major risk factors interacting and contributing to the level of risk for an assembly worker is working posture (the two others are time and force). To achieve a working posture that is likely to happen in reality when using a DHMS tool is therefore crucial. Realistic posturing is required to obtain accurate quantitative assessments of human performance, as it has been shown that the performance models are sensitive to the postural condition. The need for faster and more consistent human simulation tools has motivated most commercial digital human modeling tool suppliers to implement various posture / motion wizards. However, these wizards are designed for certain types of tasks (e.g. ingress, egress or driving postures), and can not be utilized as a general solution for obtaining correct assembly/working postures. This paper shows examples of where working postures, achieved through manual use of DHMS tools, and discrete motions, achieved through use of a motion wizard, often considerably differ from working postures compiled during VR/AR sessions. This way of working (using VR/AR) is used to achieve more realistic working postures and a further development of the DHMS tools and working procedures should lead to faster and more consistent human simulation tools. The paper also justifies several research projects, which purposes are to decrease the gaps between wanted and existing functionalities.

Keywords. Digital Human Modeling Software (DHMS), VR/AR, Human Posturing, Ergonomics Simulation, Ergonomics Assessment

1. Introduction

Digital Human Modeling Software (DHMS), both for product development and production process development, are frequently used within automotive industry [1]. The software is typically installed on desktops and operated with mouse and keyboard (manually using a DHMS), and the software is normally used early in development processes to consider ergonomics in design, development, and pre-planning, and the results are visualized by numbers, pictures and, less regularly, movies. To continue to provide essential support in development processes, DHMS technology needs to be adapted to new digitalization techniques and trends. Therefore, DHMS technology needs to be able to work together with head mounted display VR (virtual reality) and AR (augmented reality) technologies, as new immersive ways to control inputs, present simulation results and enhance understanding. Such technologies are available and

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established within the gaming/entertainment industries. Furthermore, DHMS technology needs to be developed to function in digital twin solutions. This means that DHMS technology needs functionality for simulations in the virtual world in order to feed the reality with information (i.e. as used today), but also have functionality to work the other way around, i.e. to be fed with information from the real world in order to continuously learn and improve, and thereby gain future designs and simulations made in the virtual world. Information from the real world could be fed from smart textiles/sensorized garments. Smart textiles have the potential to radically change the way industry performs evaluations of ergonomics. Clothes with integrated sensors exist on the market and prototypes have shown that piezoelectric fibers can be used to detect finger flexion and piezoresistive fibers for registration of foot pressure [2,3]. Additionally, other wearable sensors, such as smart watches and wristbands, are changing the traditional interaction with operators in assembly industries. Wearable solutions may be a natural way to improve the usability of measurement systems by avoiding the use of cables and sticky electrodes and ensuring correct electrode placement by novice users [4,5].

One of three major risk factors interacting and contributing to the level of risk for an assembly worker is working posture (the two others are time and force) [6]. To achieve a working posture that is likely to happen in reality when manually using a DHMS tool is therefore crucial. Realistic posturing is required to obtain accurate quantitative assessments of human performance, as it has been shown that the performance models are sensitive to the postural condition [7]. The need for faster and more consistent human simulation tools has motivated some commercial human modeling tool suppliers to implement various posture/motion wizards. These task animation wizards allow a more rapid definition of task sequences [8,9]. However, these wizards are designed for certain types of tasks (e.g. ingress, egress or driving postures), and can not be utilized as a general solution for obtaining correct assembly postures or motions. These wizards seem not yet to be a successful way of eliminating, or at least minimizing, the inconsistency in results within or among simulation engineers. Fully functional self-posturing (and motion) calculation is needed by DHMS tool users [10]. There are numerous examples of posture and motion prediction research and implementations, e.g. [11-15]. Most of the research results are not yet available in commercial DHMS tools but implemented in research applications.

This paper shows examples of where work postures, achieved through manual use of DHMS tools (posturing the manikin with manual joint manipulation or by instructing the manikin to perform a certain grasp task), or by using task animation wizard, considerably differ from “real” postures compiled during VR/AR sessions. VR/AR is used to achieve more realistic (likely to happen) working postures and a further development of the DHMS tools and work procedures should lead to faster and more consistent digital human simulation tools. The paper also justifies several mentioned research projects that is supported by the authors’ employer both by financial means but also by collaboration.

2. Examples of achieved working postures

This section presents three working postures achieved with manual joint manipulation (manual use) of DHMS tools and one motion sequence achieved by the use of a task animation wizard. The DHMS tools used are IMMA [16] (Figure 2 and 3) and

JACK/JILL [17] (Figure 4). The motion sequence is generated in the IMMA manikin software.

2.1. *Manual use of DHMS tools*

Volvo Cars uses a generic work process for performing DHM task analysis suggested by, among others, Green [18] and Hanson et al. [19]. The work process includes the following seven steps: 1) understanding the task, 2) understanding the work environment, 3) understanding the worker population, 4) understanding the limits of the software used, 5) performing the analysis, 6) analysing and applying judgements to the results, and 7) reporting the results of the analysis. This work process is used to support both the customers of the simulation tasks and the simulation engineers performing the tasks. By this approach the simulation engineers are given vital information about the task; what is the working height, what is the weight of the assembled part, is the task allowed to be carried out as a blind operation, is the operator allowed to lean on the car, is the operator leaning on the car, etcetera.

It could be argued that the unrealistic postures achieved with manual joint manipulation (manual use) of DHMS tools are due to inexperienced simulation engineers or poor manual execution of DHMS tasks. However, the simulation engineers at Volvo Cars have been working, in average, 21.6 years (n=5, s.d.=0.8) as simulation engineers within the Final Assembly Manufacturing Engineering organization; and during the last 23 years Volvo Cars has used several different DHMS tools. Figure 1 shows the different DHMS tools and the period of usage. Thus, it should be possible to reject that inexperience and poorly executed simulations are the cause of the unrealistic postures.

Figure 2-4 (the figures have been partly blurred due to confidentiality reasons) show three working postures that are unnatural (unlikely to happen). Unfortunately the “real” postures derived from VR/AR sessions are not possible to show due to confidentiality reasons. However, the figures are rather self-explanatory – the working postures are really unnatural; but it is a subjectively based statement of the both authors. Comparisons between experienced operators' (used in VR/AR sessions) preferred working postures and the working postures achieved through manual joint would probably objectively reject them as natural working postures.

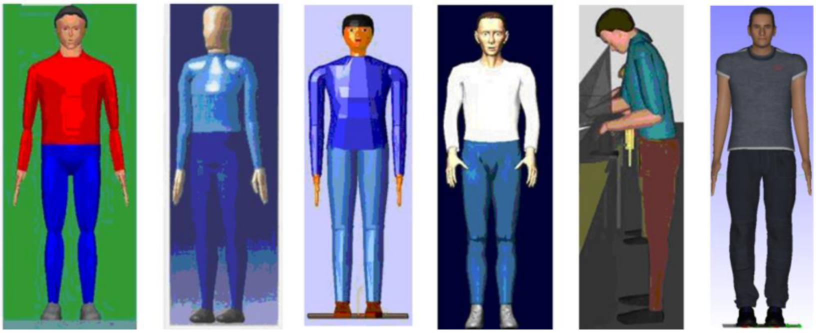

Figure 1. The different DHMS tools used at Volvo Cars during the last 23 years. From left to right and the period the DHMS tool was/is used: IGRIP/VMAP 1998-2000, Catia V5 Human 2000-2002, Robcad/Man 2000-20004, eM-RAMSIS 2004-2010, JACK/JILL 2010-today, IMMA 2015-today.

Furthermore, the simulation engineers' greatest concern is that the simulation tasks appear to be correct as well as being correct [20,21]. If the simulation task does not appear realistic, the analysis might also be questioned. Consequently, simulation engineers manipulate the manikins to achieve as realistic postures as possible and be in congruent with the information given by the customers in the generic work process.

Figure 2. Assembly of tailgate sealing. (IMMA manikin)

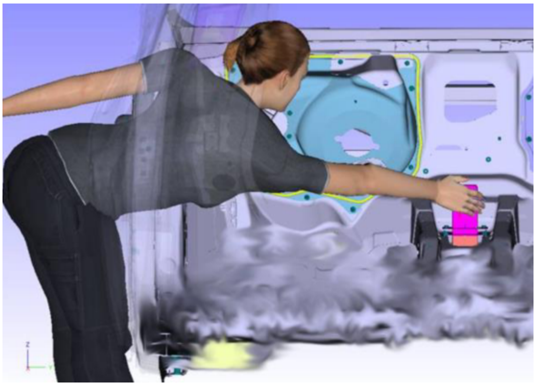

Figure 3. Assembly of a part in the tunnel console. (IMMA manikin)

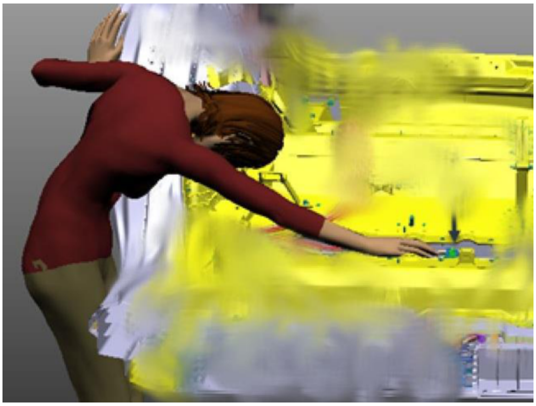

Figure 4. Electrical connection in the proximity of the tunnel console area. (JACK/JILL manikin)

2.2. *Using task animation wizard*

Figure 5 shows the interface of the task animation wizard in the DHMS tool IMMA. To instruct the manikin (manikin family) to get into the rear part of the car the simulation engineer has created 34 sub-tasks (such as attach, detach, look at, follow, pause, grasp etcetera). The 34 sub-tasks' basic motion is shown in Figure 6.

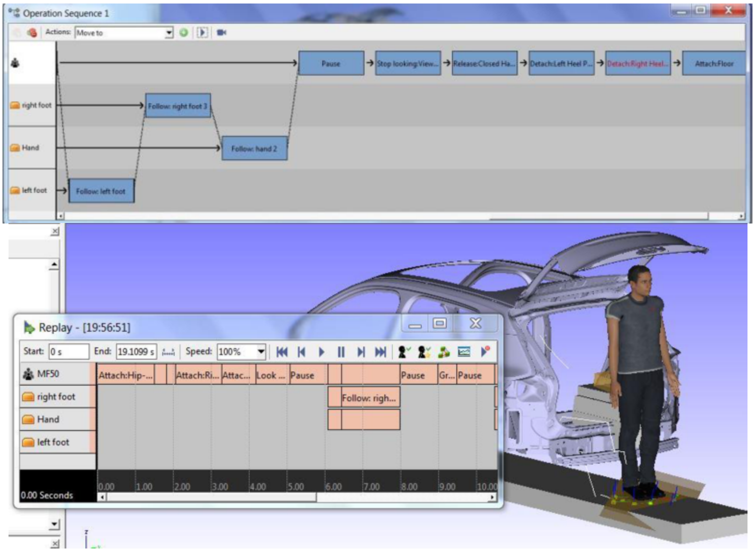

Figure 5. The interface of the task animation wizard in the DHMS tool IMMA. The operation sequence consists of 34 sub-tasks.

Figure 6. The 34 sub-tasks' basic motion pattern. (All 34 pictures are not possible to show due to restricted space in the form of a conference paper).

The task animation wizard is used when the manikin task consists of a longer and rather complex motion. It is the only way to, inside the DHMS tool, manually instruct the manikin to perform a movement over a longer period of time. Thus, it can be seen as a complement, or substitute, for motion capture.

3. Discussion and concerns about achieved working postures

3.1. *The working postures achieved by manual use of the DHMS tool*

The working postures in Figure 2-4 achieved by manual use of the DHMS tools are not likely to happen in reality. However, the simulation engineers within the Final Assembly Manufacturing Engineering organization, at Volvo Cars, state that it is often when the human (manikin) has to reach a certain part or location in its boundary of reach of motion that the unrealistic working postures occur. Sometimes the unrealistic working postures occur when the manikin has to support the body with one hand. Figure 4 shows a typical working posture that is the result of a change of a hand position – in this case the left hand has been moved to the door pillar to support the body; and that change makes the manikin to occupy an awkward body posture. The simulation engineers try to avoid these awkward body postures but have no, or little, knowledge about what is causing the manikin to suddenly occupy an unwanted and unrealistic body posture. The simulation engineers often restrict the manikin to move as much as possible by entering certain constraints such as attach some body parts to different car components or demand a particular line of sight to avoid a rapid change of the neck angle. However, that trick is not very useful since it will, if used too much, completely freeze the manikin and it will not be possible to move the manikin at all. Another concern is that the manikin is taught (programmed) to avoid collisions and therefore behaves as if the car body is lethal to touch; Figure 2 and Figure 3 are typical examples of such behaviour. This is the case for all DHMS tools that have collision avoidance, e.g. IMMA and eM-RAMSIS [22]. If the manikins in these two cases lean with the hip, or the thighs, on the car body they will occupy a much better ergonomics posture. In the software IMMA it is possible to synthesize collision-free and ergonomic motions for a system consisting of a manikin and the part being assembled using the manikin motion generator inside IMMA [23]. However, many assembly tasks are related to engage clips and connectors. Thus, there is no part that shall be taken from the material facade to a nominal part in the car. Therefore the motion generator can not be used – there is simply no part to connect to the motion generator.

The manual use of the DHMS tools to achieve working postures are full of flaws and it is well known that this method is not very suitable for ergonomics analyses [24]. However, it is still the most common method to manipulate a manikin since it is a basic functionality in all DHMS tools and manual adjustments of body angles continue to be a common method to manipulate a manikin [25].

3.2. *The working postures achieved by using a task animation wizard*

A motion over a long period of time is not possible to create with manual use of a DHMS tool. If the DSHMS tool is not equipped with an animation wizard an imported stream of motion must be used, e.g. motion capture. The working postures (or discrete motion cycle/time frame capture) achieved by using a task animation wizard is therefore the most realistic motion that can be generated manually. However, it is an extremely time consuming procedure and the discrete motion jumps are not collision free and the motion pattern is rather “robot like” in its motion behaviour. The simulation engineer can try to avoid this “robot like” behaviour by adding more (sub) tasks, but that would take even more time, and the benefit between creating more (sub) tasks and a better motion behaviour is not worthwhile. Due to the vast time needed to carry out a motion sequence by using a task animation wizard, and the rather jerky motion pattern (and not 100% collision free) achieved, are two of the reasons why animation wizard based motions are not commonly performed at Volvo Cars.

3.3. *An intermediate period when complementary technologies are used together with DHMS tools for ergonomics simulations*

Many of the shortcomings and difficulties described in this paper could be avoided, or at least reduced, by the use of complementary technologies such as:

- Motion Capture (recording the movements of objects and/or people)
- VR[2] and/or Mixed Reality where physical and digital objects co-exist and interact in real time (also called AR – Augmented Reality)
- Virtual Gloves (capturing full hand and finger actions in virtual reality)

Considering the many recent advancements in capability from the movie animation and gaming industries. The quantity and quality of computer generated movies and computer games have increased greatly over the past 15 years. The realism of humans

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[2] In this descriptive paper we do not explicitly distinguish between VR and AR, although there are distinct differences; but in this context we consider it being more of a semantic issue and consider them being synonyms.

represented in these models and their associated movements are attracting customers and driving new business opportunities. DHMS tool developers and providers should investigate the technologies used in these industries for application in commercial DHMS software. Today, there are many available motion capture programs that are both affordable in price, easy to use and that reproduce sufficiently accurate motion recordings, e.g. [26-28]. In the VIVA project [29] an add-on application for motion capture has been developed for IMMA and it is Volvo Cars' intention to implement this motion capture add on. This complementary technology will be used to achieve more realistic working postures for assemblies in the outmost reachability area of the operators. When (not if) the DHMS tools have been improved, and motion capture no longer is needed for these kind of assembly simulations, Volvo Cars will abolish the motion capture technology.

To further improve the use of motion capture Volvo Cars will also combine it with mixed reality so physical and digital objects co-exist and interact in real time. Already today Volvo Cars uses mixed reality without combining it with motion capture. Once the COVID 19 pandemic is over, testing of motion capture will be performed and successful tests will lead to a launch of motion capture. Figure 6 shows an example of mixed reality.

The hands are an operator's most valuable tools. Many simulation tasks are ordered in the purpose to get an answer if a part is possible to handle with the hands; are there sufficient space, are the handles good etcetera. The simulation engineers might spend up to 50% of the simulation time to tune the hands and fingers to a realistic configuration [21]. Thus, virtual glove technology is something that interests Volvo Cars. Furthermore, hand, wrist and finger injuries are the most common MSDs in Volvo Cars' final assembly plants (48% of all reported MSDs).

[redacted]

Figure 6. An example of mixed reality. The "operator" is wearing a head mounted display (HMD) and is working in a room where props like aluminum frames and wooden parts have been installed to mimic a car body. The HMD is displaying a virtual car made of CAD parts – positioned in relation to the props.

4. Research projects supporting the need for faster and more consistent human simulation tools

The following three mentioned research projects have all been initiated to deal with the shortcomings and difficulties described in this paper. Beyond dealing with these issues the research projects are dealing with numerous other research questions; all in attempt to close, or decrease, gaps in functionalities and efficiency of DHMS tools. These research projects' aims and purposes are justifying the authors' employer to participate in the research projects and partly financing them. The following three paragraphs, 4.1-4.3, are coarsely describing the three research projects' objectives and research topics.

4.1. *VIVA – VIrtual vehicle assembler*

VIVA – VIrtual Vehicle Assembler [29] is a research project that started in 2019. It will continue for three years and will end in April 2022. The total funding from VINNOVA is 4.6 MSEK. The overall aim is to develop a supportive DHMS tool that:

- automatically can predict human behaviour considering dynamic effects and analyze human work in manual work stations from a musculoskeletal viewpoint
- automatically can optimize workstations where humans are supported with exoskeletons or collaborative robots.
- considers human diversity in terms of appearance, shape, clothes, and safety equipment used during work.
- easily can be understood, used and manipulated as well as adapted to recent developments within immersive VR and digital twin solutions.

4.2. *SVE – Synergy Virtual Ergonomics*

SVE – Synergy Virtual Ergonomics [30] is a research project that started in 2019 and will end in September 2023. The total funding from the Knowledge Foundation (KK) is 12 MSEK. The project has three themes: 1) Modeling behaviour and appearance, 2) Assessment and 3) Interaction.

The research contributions will include techniques and methods for making well-informed design decisions related to ergonomics, mainly at the virtual stages of the product realization process, including representing human diversity, digital twin solutions, modeling and assessing cognitive ergonomics, instructing manikins from demonstrations, applying persona descriptions to manikins, and interacting with manikins in immersive virtual reality (VR).

4.3. *DIPPA – Digitalization of Product- and Production design to increase Automation*

DIPPA – Digitalization of Product- and Production design to increase Automation [31] is a research project that started in April 2019 and will end in April 2021. The total funding from VINNOVA is 3 MSEK. The purpose and goal of the DIPPA project is to increase the interaction between product and production design to increase automation in the final assembly. In the context of DHMS tools DIPPA will carry out research in the topic of Human Robot Collaboration (HRC).

5. Conclusion

In the meantime, before a ”perfect” task animation wizard is realized, motion capture will probably be the predominant technology to use when it comes to generate complex motions for digital human models in a manufacturing context. DHMS technology needs functionality to be fed with information/data from the real world in order to continuously learn and improve, and thereby gain future designs and simulations made in the virtual world. Information from the real world could be fed from smart textiles/sensorized garments. Wearable sensors, such as smart watches and wristbands, are changing the traditional interaction with operators in assembly industries. Wearable solutions may be a natural way to improve the usability of measurement systems by avoiding the use of cables and sticky electrodes and ensuring correct electrode placement by novice users. DHMS tools could also be connected with motion databases with MTM-based annotations in order to synthesize natural looking motions, as suggested by Keyvani et al. [32].

Acknowledgement

It is not the authors' intention to completely disqualify the use of DHMS tools. These tools are indispensable in the development of new vehicles and play a crucial role in virtual product simulation and production simulation. The development that these tools have undergone over the past thirty years is outstanding and it is important to recognize the focused work of DHMS developers and researchers that is supporting and enabling the automotive industry's virtual way of working. The authors also would like to thank both *VINNOVA* and *The Knowledge Foundation* for financially supporting the research projects mentioned in this paper.

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