Integration of Virtual Reality and Digital Human Model Simulations for Ergonomic Analysis of CAD Models

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Abstract. The paper deals the exercising Virtual Reality (VR) validation for ergonomic study of Computer Aided Design (CAD) virtual environment models, for the safe and comfortable operations for human. The CAD based virtual environments will subject to ergonomic analysis could reduce the costs of testing and errors in integration of sub systems compared to real-time trials. In this venture, a Digital Human Model Simulation (DHMS) was analysed in a workspace by incorporating VR simulation softwares. A transport and freight of military personnel and equipment in Armoured Personnel Carrier Vehicles (APVCs) model was employed as environment for ergonomic assessment. VR device with head-mounted display was used to perform the ergonomics analysis in virtual environment. The ergonomics study and the experience lead to changes in design features. This application could benefit in the defence, aerospace and naval sector, where ergonomically viable compact spaces for human inhabit of key importance.

1. Introduction
The fast pace modernization in research in various fields is increasing and necessary to use the IT tools for simulation and analysis. Nowadays, virtual reality to be able to virtually replicate the entire planned design and models of major projects and easily visualize them through superficially being present within. Present VR technologies supports virtual presence of user in the CAD design and feeling the entire experience of the design/object to be analysed and assists in suggesting changes associated with design issues. Contemporary Virtual Reality (VR) experience allows incorporating the dynamic models to interactively manipulate and also fit within 3-D systems environment.

In this work, a Digital Human Model (DHM) was subjected to an ergonomic analysis in an Armoured Personnel Carrier Vehicles (APVCs) workspace by incorporating VR simulation softwares. Ergonomics of human factors is the scientific discipline that is mostly concerned with understandings of the interactions among humans and also that of the other various elements of a given system, and it applies data, theories, principles and certain critical and useful methods so as to design in order to enable us to optimize the factor of human well-being and that of the overall system performance. The Digital Human Modelling (DHM) is involving CAD representation of the form of human bodies or its certain parts for the purpose of virtually evaluating the ergonomics of a newly designed object’s product-human compatibility.

Sougata et al [1] presented a review which informs about a solid knowledge base which is regarding the DHM’s present status and its use for ergonomically evaluating the products and their workplaces in industries and emphasizes that more R&D activities are needed so as to make customized humanoid modelling designs which will be representing regional population. Mahdavian et al [2] presented various developments and the capabilities of the DHM tool IPS IMMA (Intelligent Moving Manikins) for an
assembly process in VR environment and noted that in a process of product design, lack of the accuracy leads to decreased precision and confidence in the product designing processes, thus causing errors and the sequence in which components are imported does not make a difference in the simulation. Whereas, for simulation purposes, depending on the size of the component, work required for a modification and the volume, import of the point cloud, Computer aided design geometry and mannequins ease the flow of work. The precise motive of the DHM tool is to support smoother and faster decisions in the product designing process, so well as design solution for well-being of humans.

Giovanni et al [3] carried out extensive studies and introduced the Dynamic Digital Human Models, which were monitored both in force and in their acceleration. DHMs were used to simulate the experimental incorporation fitting jobs in quasi-real-time, and also used simulated times, exertions and the postures in order to calculate the index-based ergonomical assessment of the taken model. Luigi Pelliccia et al [4] developed the HuPOSE model, which was involved in the calculated simulation of an Jacobian matrix which was augmented, so as to specify the trajectories and the paths for the different points of control, considering the anthropological, bio mechanical and musco-skeletal aspects. The study was analysed based on single point analysis of multiple postures, such as that of squatting, sitting, hand straightening and a large variety of postures and positions were assessed.

Nick [5] stated that the human body and its modelling serves to the engineer concerned with human factors with a novel simulation tool which binds the various opportunities of CAD and the techniques which are encoded around the user for the iterative design and also that of prototyping and focussed to create more interactive virtual environments. The very early stages of the technologies involving digital humans and their simulations in order to provide ergonomic analysis of the VEs were highlighted. Suman et al. [6] worked on the usage of digitally capturing the human motions, which will act as the source which drives the VE interaction among the DHM mannequin and its simulated VE for work. It also emphasizes on the application of dynamic ergonomical analysis of mannequins and DHMs like the Job Risking Classifications Modelling, which was rooted on the motion and interactions captured from such a virtual environmental interaction, which provides a positively encouraging way to engage in the further improvement of the current CAES systems. The study highlighted on the various shortcoming of the processes and the hindrances that exist in further developing the models and making the process more interactive and nearer to the real world. Jeffrey [7] concluded by adding that the DHM models are being taken into usage by the ergonomists increasingly over time, along with the dependency on other engineers to design virtual environments and equipments so as to help the human operators.

Faisal et al [8] presented and compared different human body joint monitoring methods for early diagnosis of musculoskeletal disorders. The current human models are limited by understandings of the ergonomics and cognitive human behavioural patterns offered by the computers for avoiding musculoskeletal disorders. Model accuracy is limited by a deficit in the current available data on 3-D human anthropometry, biomechanics, strength and postural formations.

Lack of basic information about the human postures and motions is addressed to be also one of the key problems. With the advancement of ergonomic tools, computer models will become more and more accurate over time. The CAD models are available to help designers to study and monitor fit parameters, biomechanics and many more. The current anthropometric databases have still many limitations in understandings of the human posture and motion. There is a need for the models to represent the population of the end user and thus such parameters vary accordingly, from region to region. Applying DHM has proven to be beneficial as it helps in the cause for significant reduction of project time-scale; the design costs; the manufacturing cost; the occupational hazards and it also helps in improving the quality, the productivity and the efficiency across multiple industrial sectors.

2. Digital human body model and ergonomics
The Digital Human Models (DHM) are basically computer-generated models of human beings which are used in CAD. Computer aided human body modelling is a tool to analyze and assess human factors issues. Through instilling an interactive and immersive visualization of a chosen CAD design with the representative mannequins, the arising human issues, such as fit, reach and vision can be evaluated and design changes can be recommended at the early conceptual stages of design. CAD based human body’s
modelling is a comparatively new form of technological system and there is a wide margin for the improvement of the commonly available tools like Android, Combiman, Poser, Safework, MannequinPro etc. The presence of the multiple degrees of freedom that do characterise the human body joints, have a significant impact on processing of the demands on the DHMs software simulations. The currently available modules support analysis on clearances and reach, visual obstructions, field of vision, biomechanical parameters, postures during a certain task/work in whole, energy expenditure metabolically, motions of various body parts, time study and anthropometric parameters.

The human body is represented as mechanical links conformed series, which are assumed to be joined at pin joints which vaguely correspond to the normal human skeleton. The complexity of such a framework may include more than 100 different links and about 150 degrees of freedom. The human body joints which are not to be modelled using rigid structure link, are represented by humanoid models. In an approach to incorporate the real-world parameters, apart from the surface geometrical parameters, most models are incorporated with different clothing aspects, which often leads to interaction of the reach, fit, range-of-motion and collision’s detection etc. in a pursuit to enhance the real-world element. The various joints for computational analysis of a DHM include wrist, elbow, shoulder, stemoclavicular, ankle, knee, upper back and neck.

The biomechanical models and parameters are integrated into the simulation and DHM software systems. These parameters thus enable the estimation of the mechanical stresses, which are induced upon internal parameters of body amidst different processes and activities. The motion of human body is equal importance as of any other parameter in the design of a work environment and the DHM simulation must take enough considerations. The motion algorithms of the human body are usually included with computer packages and capable of producing lift motions, reach, and grasp motion for a model which is stationary or moving in the environment. The DHM analysis has stimulus in productions systems. Manual assembly is time and cost consuming phase in production. It is important that the design of assembly process with a consideration in ergonomics, will increase whole system’s efficiency, human’s well-being and quality of output at required levels.

3. Methodology
In this work, the ergonomics of a CAD generated environment of military APCV was studied and analyzed in virtual reality environment. The virtual reality tools enable the analysis of designs in early development phases and to avoid integration of any irregularities or unwanted design parameters. This will help defense sector in analyzing key vehicle design, ergonomics and features before making decisions to develop APCVs. Figure 1 shows the procedure adopted in this simulation study.

![Diagram](Figure 1. Methodology)
The CAD softwares Unigraphics, SolidWorks and CATIA RULA were used to model VR environment and manikin (Digital Human Model). For virtual reality interaction, VR software along with head mounted VR system was employed. A high-end computing system with minimum of 8 GB RAM and graphic card support need to be used for the study.

4. CAD modelling of APCV

In this study, a CAD based virtual work environment was generated with Solid Works as a real-life scaled version of a possible Armored Personnel Carrier Vehicle (APCV) in cabin structures. The basis of the design was the Panzer IV, a World War II tank of German make. The technical specifications of the tank are listed in table 1.

| Parameter        | Value                     |
|------------------|---------------------------|
| Kerb weight      | 23.0 tonnes               |
| Length           | 6863.86 mm                |
| Width            | 4371.16 mm                |
| Height           | 2451.35 mm                |
| Crew             | 9                         |
| Engine           | 12-cylinder Maybach (296 BP) |
| Power/weight     | 12 HP/tonne               |
| Suspension       | Torsion-bar suspension    |
| Fuel capacity    | 310 litre                 |
| Operational range| 165 km                    |
| Speed            | Road: 41 km/hr Off-road: 23 km/hr |

The generated CAD model was processed on SolidWorks software for VR visualization. The validation of optimal designed component is carried out by a Virtual Reality (VR) head mounted display system to assess the design parameters.
5. Ergonomic analysis in VR environment
The objective of the study is to validate the ergonomic feasibility of the workspace layout for an APCV (Armored Personnel Carrier Vehicle) in VR environment. A RULA (Rapid Upper Limb Assessment) analysis on CATIA along with the determination of reach envelope as well as binocular vision of the DHM manikin was performed in the CAD model of the Panzer IV World War II model of German make tank as the reference. The sectional top and isometric views of APCV model with seating area are depicted in figure 3. The various positions that have been assumed for RULA Analysis is marked in the sectional view of the model in the figure. Initially, two positions, at boundary seating and central seating were considered for the ergonomic analysis.

![Figure 3. Sectional top and isometric views of APCV model with seating area](image)

The SolidWorks CAD file of vehicle model was converted into .IGS file and imported into CATIA. A manikin DHM was added to simulate the ergonomic feasibility. For the manikin DHM, an 85 percentile male was considered as reference. During the ergonomic feasibility simulation of the model, the posture of the manikin has been changed appropriately, to depict a seated armed soldier clutching an assault rifle. The specifications of the posture are listed in the table 2.

| Posture Parameter | Right   | Left    |
|-------------------|---------|---------|
| LeArm             | 32.21°  | 21.113° |
| Clavicular        | 0.495°  | 0°      |
| Foot              | 0°      | 0°      |
| Forearm           | 77.238° | 119°    |
| Full spine        | 0°      | 0°      |
| Head              | 0°      | 0°      |
| Leg               | 90°     | 90°     |
| Line of sight     | 0°      | 0°      |
| Lumbar            | 0°      | 0°      |
| Thigh             | 90°     | 90°     |
| Thoracic          | 0°      | 0°      |
| Toes              | 0°      | 0°      |
| Hand              | 19.325° | -30°    |
| Thumb 1           | 0°      | 0°      |
| Thumb 2           | 0°      | 0°      |
| Thumb 3           | 0°      | 18°     |
| Index 1           | 35°     | 0°      |
| Index 2           | 23°     | 64°     |
| Index 3           | 47°     | 0°      |
| Middle Finger 1   | 35°     | 0°      |
| Middle Finger 2   | 23°     | 64°     |
| Middle Finger 3   | 47°     | 0°      |
| Annular 1         | 35°     | 0°      |
| Annular 2         | 23°     | 64°     |
| Annular 3         | 47°     | 0°      |
| Auricular 1       | 35°     | 0°      |
| Auricular 2       | 23°     | 64°     |
| Auricular 3       | 47°     | 0°      |
Figure 4. Defining posture of manikin DHM

The posture of the manikin was fixed according to the selected parameters as shown in figure 4 and a static load was added to the arms to simulate the weight of the rifle and subsequently, a RULA score was generated for the posture. The RULA analysis was performed for different positions within the rear area of the vehicle, for the boundary seating and central seating. The simulation results are shown in figure 5 and figure 6.

Figure 5. RULA analysis for boundary seating position
A RULA score of 3 was obtained for the positions considered, with individual scores being allotted for upper arm, forearm, wrist, wrist twist, muscle, force/load, wrist and arms, neck, trunk and leg. The iterations were performed multiple times by adjusting the parameters such as, the shoulder droop, wrist angle, forearm inclination, finger alignment, etc. to attain the most ergonomically sustainable posture and to reduce the load of the gun on the muscles. The posture was set as static and the number of cycles were considered based on real life scenarios. Subsequent to static posture, the reach envelope and binocular vision for the manikin was determined, the simulations were shown in figure 7, figure 8 and figure 9.
6. Validation RULA model in VR environment

In order to confirm RULA results, the model was simulated in the virtual reality setup and manually checked every clearance. To validate the results of RULA analysis and reach envelope determination, the model was imported into the Virtual Reality (VR) software and scaled to the actual dimensions of the tank in VR simulation. Figure 10 shows use of VR headset and hand-held wireless sensors in experiencing APCV model clearances in the VR environment. The reach, envelope and clearances of the walls/equipment/other possible obstacles from the individual body parts were experienced in the VR environment to perceive any potential interference.

Based on the analysis, it was found that the right fore arm and left wrist were subjected to a very high static force due to the weight of the assault rifle. However, the other parameters were found to be within the desired limit. The RULA score obtained was 3, which is considered to be just acceptable. Among the individual RULA scores, none exceeded 3, which is again a desirable result and shows that the armored vehicle being considered is ergonomically sustainable. The reach envelope and binocular vision for the manikin were determined and further cemented the results of the RULA Analysis.

The concept of VR analysis can further be used as demonstration to customers earlier to the decision of selling/buying a new product involving human operations.
7. Conclusion
The results of RULA analysis, reach envelope determination and the DHM model were successfully assessed in virtual reality environment with the models scaled up to actual dimensions in simulation. The experimented methodology saves vital time by evading constructions of huge and expensive physical mock-ups prior to commissioning of real setup like APCV. Integrating the VR and ergonomic analysis, crucial decisions can be made promptly, thereby saving cost, time and avoiding errors. Further research in the field of DHMs may focus Indian population, so as to get more precise and accurate results for the human workers based on local conditions. VR technology can further be developed as a fully interactive software tool for real-time solutions.

8. References
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