Digital Human Modeling Approach In Ergonomic Design And Evaluation - A Review.

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***Abstract*—Digital Human Models (DHMs) are becoming an effective tool for ergonomics design and analysis. The use of DHM reduces the product design and manufacturing task cycle times by eliminating the production prototypes. In the first part of the paper traditional ergonomic assessment methods such as predetermined time standard methods (PTS) and analytical methods are discussed. In DHM based design of products and work station, anthropometry is one of the most important aspects to be considered in the initial phase of the design process. Different databases were incorporated in DHMs to choose the size and shape of the manikins in simulation process. In every ergonomics DHM, inverse kinematics principle which is the principle behind the working of robotic arm are using for posturing the manikin. The article discusses various works which describes the DHM based ergonomics design and analysis. DHM software, such as Jack, RAMSIS, SAMMIE, CATIA- DELMIA, AnyBody and the UM-3DSSP are discussed in the paper. Limitations in current DHM models are also discussed.**

Keywords: Digital Human Modeling; Ergonomics; Work system analysis

I. Introduction

Even though there are a lot of advances in automation of manufacturing process, human operators have essential role in most of production systems, due to the flexibility and adaptability of human beings. Human beings at work are at risk of injury, if they employ cyclic, continuous, forceful, or awkward working posture. Nowadays, work-related musculoskeletal disorders (WMSD) are the most common occupational health problems in the developed and developing countries [5] . This is a major problem in most developing countries due to poor working conditions and the absence of effective work injury prevention programs. The risk of work related musculoskeletal disorders can be reduced by applying ergonomics principles. The application of ergonomic principles in the workplace can result in the high rate of productivity, improved work quality, better health and safety of workers, lower workers' compensation claims, compliance with government regulations, better job satisfaction, low worker turnover ratio, enhanced morale of workers, low absenteeism rate. Workstation design, equipment and tools, work environment, and work organization are work components that affect ergonomic risk factors. Effective application of ergonomics in work system design can achieve a balance between worker characteristics and task demands. An ergonomic design can include factors such as adjustable seating, angled hand tools, or a work space that suit the worker. From the literature it is understood that two main scientific approaches are followed by the ergonomist for the design of work station. The first approach is based on the direct analysis of the real workstations, while the second one is computer based analysis to design workstations ergonomically. Both methods are discussed in this paper with more emphasis on DHMs. Traditionally physical mock-up methods are used for work system analyses; the drawback of these types of methods is time consuming. An effective manufacturing workstation design should jointly consider both operational and ergonomic characteristics. The digital human modeling can be taken into the early stage of product development and design work system, so ergonomics issues can be considered for the design and can avoid real prototypes which reduce the cycle time cost of design.

II. ERGONOMIC ASSESSMENT METHODS

This review paper discussed an overview of some popular methods available for the ergonomic assessment of work-related musculoskeletal disorders. The paper gives more emphasis on the publications based on Digital Human Modeling.

A. *Predetermined time standard method*

Physical risk assessment was usually conducted by analysing different postures and forces exerted by the operator during moment of the task. A basic analysis can rely on questionnaires and video analysis. But more accurate and complete ergonomics analysis generally requires complex expensive instrument and arrangement for measurement, which may hamper movement task performance. Predetermined Time Standard (PTS) systems have been used for work measurement to estimate the time needed by qualified workers to perform a particular task at a specified level of performance. Commonly used PTS is Methods Time Measurement (MTM), which is developed by Maynard et al. It is a procedure for improving methods and establishing time standards by recognizing, classifying, and describing the motions used or required to perform a given operation and assigning pre-determined time standards to these motions. This system is used to evaluate motion time of manual operation and analyze workload of right or left hand by calculating time distribution. A modified and simplified form of MTM is Maynard Operation Sequence Technique (MOST). MOST utilizes large blocks of fundamental motions and 16 time fragments. Nowadays numbers of commercial software-packages are available to calculate expected time consumption for a planned task.

B. Analytical methods

Ergonomics evaluation methods such as RULA (Rapid Upper Limb Assessment Method) a survey method was developed for analyse work related musculoskeletal upper limb disorders by Mc Atamney and Corlett [1]. In this method a quick assessment of the posture of upper limb like neck, trunk, muscle function and the external force experienced by the body are provided.

The OCRA (Occupational Repetitive Action Method) method developed by Occhipinti [31] is used to analyse the WMSD risks of the upper limb of the workers. This is one of the most important analytical methods and is particularly used to redesign or thoroughly analyze the ergonomics of the workplace.

The Strain Index developed by J. Steven Moore et al. [30] is another method to analyze the upper limb WMSD risks of working tasks. It is based on the principles of biomechanics, physiology and epidemiology. The biomechanical aspect of the principle that strain exerted outside the limbs is translated into internal forces of stretching and compression on the tendons and muscles and that these forces are proportional to the effort exerted. The Strain Index is essentially calculated by determining variables such as the intensity of the exertion, the duration of the exertion, the number of exertion per minute ,the posture taken up by the hand-wrist segment, the speed at which the task is performed, the duration of the task during the working day.

The Quick Exposure Check (QEC) method developed by David Geoffrey et al. [11] is based on physical observations and has been scientifically developed and validated. From this method, action categories can be created by risk parameters such as posture, duration, frequencies and external force. These methods are poor in terms of sensitivity since they are based on assessments by an observer.

C. Motion Capture Methods

Motion Capture is a technology for recording motion of people which gives data for the ergonomics analysis. Optical or magnetic markers are attached to a subject and then sensors track these markers as the subject moves. In an optical system, reflective markers are attached to different locations on the body like the elbow and shoulder. The position of the markers is captured by several sophisticated digital cameras. The drawbacks of the method are time consuming procedures and sometimes taking much longer than the original collection of the data, including the experimental set up time. Some obstacle may affect the line of sight to the target. Although data collectors use several cameras, markers may be out of sight by other parts of the subject's body. In a magnetic system, three orthogonal coils are mounted in a transmitter and in each marker. The relative magnetic flux between the transmitter and the receiver in the marker allows one to determine both the location and orientation of the receiver. The magnetic system has the advantage of not requiring a line of sight. Magnetic systems are also sensitive to metallic objects and electrical fields. The optical motion capturing system is shown in the Fig. 1.

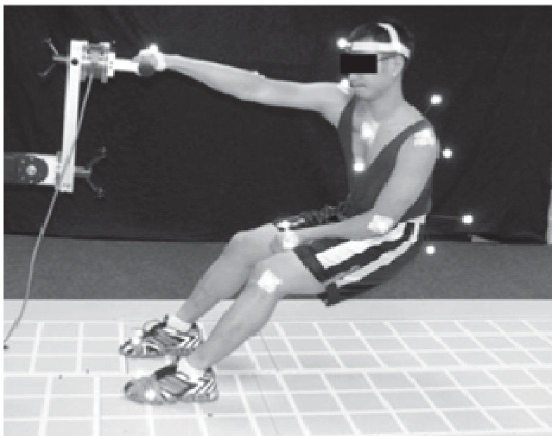

Fig. 1. Motion Capture in the laboratory. Optical markers can be seen as small white balls.

D. Digital Human Modeling (DHM)Methods

Digital Human Models are fast becoming an effective tool for performing ergonomics analysis and design [5]. Digital human modeling techniques have been developed to assist ergonomic design and evaluation for a specific worker population. It provides a 3D visualization of human being involved in activities and gives guidelines to do ergonomic analysis and to design a workstation. Digital human modeling gives opportunity to the engineers in product development to consider ergonomics and human factors early in the development process. At the same time, digital human modeling reduces the need for the production of real prototypes and can even make it obsolete. Industrial manufacturers are also increasingly using DHM to simulate workers in computer simulations of new plants or processes. The advantage of a DHM based design is that workstation ergonomic assessment made possible even at the early stages of the design process without the need for direct measurements on human subjects [6]. The common capabilities and functions of DHM includes the ability to move the manikins in predefined motions, Reach analysis, Posture analysis, Push/Pull analysis, Carrying analysis, Rapid Upper Limb Analysis and it have provision to scale 3D manikins by using anthropometric data available. However, a number of limitations concerning the use of DHM have been identified, for example biomechanical approximations, static calculation, description of the probable future situation or statistical data on human performance characteristics. Furthermore, the most common DHM used in the design process are controlled through inverse kinematic techniques, which may not be suitable for all situations to be simulated [18].

1) Inverse Kinematic: Kinematics is the process of calculating the position in space, the end of a linked structure. If the angles of all the joints are given then it very is easy to find unique solution. In inverse kinematics the end point of a linked structure is given, then we have to find the angles at the joints from the infinite number of solutions to achieve end point. In every ergonomics manikin inverse kinematics principle are using for posturing. This method is widely using in robotics. To grab an object by using robotic arm, if the software of the robotic arm knows where the object is placed with respect to the position of shoulder, it simply calculates the angles of the joints to reach the object. This would also be a great thing to have in 3D games.

2) Anthropometry Concept in DHMs: Anthropometry is the study of the measurement of the human body in terms of the dimensions of bone, muscle, and adipose (fat) tissue and used to study differences between groups such as Race, Age, Sex and Body type. In DHM, anthropometry is one of the most important aspects to be considered in initial phase of the design process. Different databases were incorporated in DHMs to choose the size and shape of the manikins in simulation process. Anthropometry depends on biological, social and demographical factors; therefore it is necessary to consider these factors early in the design products and workstations. In most of the DHM software two options are available for choosing the manikin, a percentile based method and custom-built methods. In percentile method we can choose 1st, 5th, 50th, 95th and 99th percentiles according to stature and weight measurements, of a certain gender, age group and nationality, generated from anthropometric data. Fifth and ninety-fifth percentile models are commonly used in the belief that this will accommodate an appropriate proportion of the user population. In custom-built method, we can define any desired anthropometric values and omitted dimensions can be calculated by regression equations. A right correlation is required between body dimensions of the population and the digital human model for the proper analysis of workstation and products. It is very difficult to the ergonomic designers to suggest a solution which will optimally fit the diverse anthropometry of the workers [10]. In different parts of the world the workforce is different and diversified therefore, it is important to design the workplace based on the anthropometry of the users.

3) DHM Software Packages: In recent years, it has become possible to study the ergonomic aspects of a workstation from the initial design process, by using digital human model (DHM) software packages. DHM software, such as Jack, SAFEWORK, RAMSIS, SAMMIE, CATIA- DELMIA, Any-Body and the UM -3DSSP are meant to assist a designer early in a product development process, when he or she is attempting to improve the physical design of vehicle interiors and manufacturing workplaces.

Jack is a biomechanically accurate digital human model to match worker populations. The design and analysis of ergonomic work stations can be done by assigning tasks, and analyzing their performance. Figure 2 is an illustration of such a design tool referred as Jack being used to assess a potential manufacturing workplace layout problem. The digital humans Jack (and his female counterpart Jill) [Fig.2] can give information to the designers what they can see and reach, how comfortable they are, when and why they are getting hurt, when they are getting tired and other important ergonomic information. This information helps workstation design safer, effective and easier.

Fig. 2. Jack and Jill

RAMSIS [Fig.3] helps engineers to do substantial design studies during the design phase. The core functions of this software are the realistic display of international anthropometric data and the efficient analysis of ergonomic questions concerning, for example, sight, maximum force, reachability, and comfort. RAMSIS is already used by more than 60% of all automotive manufacturers worldwide for the ergonomic design and analysis of passenger compartments and work places.

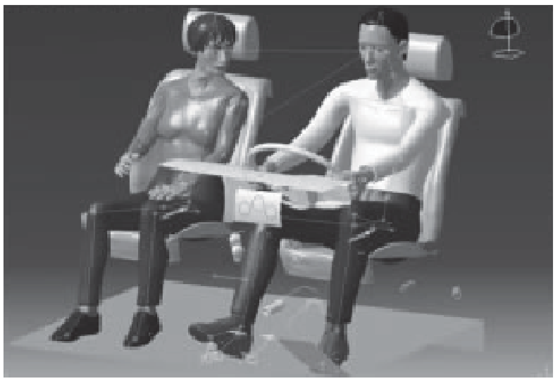

Fig. 3. RAMSIS human model

CATIA- DELMIA [Fig.4] ergonomics analysis software is used to analyse and predict human safety and performance directly from the 3D virtual environment. Users can examine, score, and iterate whole-body and segment postures for ergonomic analysis of defined work in the context of a product or workplace design. Users can also work more precisely on the anthropometric definition of their manikins

Fig. 4. CATIA- DELMIA human model

AnyBody Modeling System [Fig.5] is a software system for simulating the mechanics of the live human body working in a particular environment. AnyBody has applications in the auto industry, medicine, the aerospace industry, sports analysis, research, and even defence. The software runs a simulation and calculates the associated mechanical properties including individual muscle forces, joint forces and moments, metabolism, elastic energy in tendons, antagonistic muscle actions and much more [32].

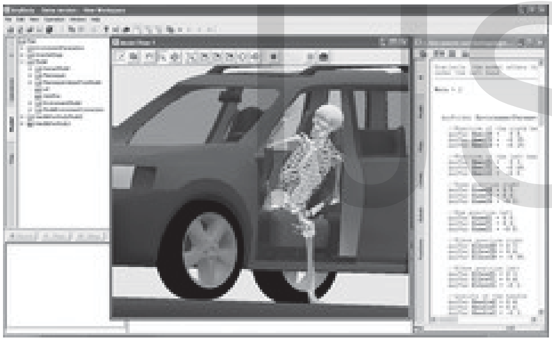

Fig. 5. AnyBody Digital human

The UM- 3DSSP (University of Michigan - 3 Dimensional Static Strength Prediction Program) [Fig.6] was developed by The Centre for Ergonomics at the University of Michigan College of Engineering. This program can be used in analyzing manual materials - handling tasks. Ergonomists, engineers, therapists and researchers, may use the software to evaluate and design jobs. This program allows users to input anthropometric data, and obtain the forces and moments computed by the program, rather than by manual calculation. In addition, the program also combines the National Institute of Occupational Safety (NIOSH) lifting data and other additional reports to identify risks associated with a particular task [32].

SAMMIE [Fig.7].SAMMIE CAD is a computer aided ergonomics products and workplace design software tool. The system for aiding man-machine interactive evaluation was originally developed at the University of Nottingham and subsequently at Loughborough University. The model has

Fig. 6. UM- 3DSSP Digital human

been applied to a diverse range of problems in areas such as workstation and aircraft cockpit design [32].

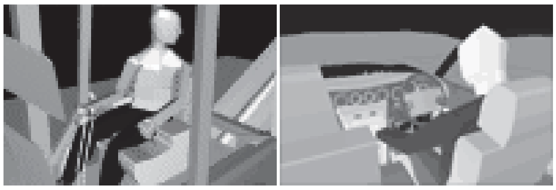

Fig. 7. SAMMIE Digital human

III. Literature review of DHM based ergonomics analysis

Liang M.A. et al. [27]in their article a motion-time analysis of manual operations is done by motion tracking technique and simulation technique with digital human modeling. The motion data is used for real time digital human simulation and for motion type recognition and analysis.

Julian Faraway et al. [21]in their article an overview of the ergonomic issues and statistical methods for human motion modeling is provided and describes the methods for modeling the basic elements of motion, decomposed into univariate curves, 3D trajectories and orientation trajectories, and methods for combining the components of the motion into a coherent whole are presented.

Shi X. et al. [36]in their article investigated the differences between driver and passenger posture and to supplement the existing model for occupant posture prediction.

Su Rune et al. [38] in their article discussed about ergonomic assessment for cockpit layout of civil aircraft. It is very important because awkward posture caused by illogical layout bring pilot discomfort, fatigue and misplay, which would violate aviation security and be harmful to pilot. The paper advises some improvement for the design of next generation cockpit based on the findings such as violation of rules of ergonomics.

Duroch L. [13] in his article discussed the ergonomics studies conducted to optimize a helicopter cabin interior to a specific cabin population, the offshore workers comfort and safety. Both digital simulations and hardware models were used for the study. The results of the study are also discussed in the article

Jingzhou Yang et al. [19] in their article discussed the ergonomic design of interior of a vehicle with digital human modeling named Santos developed at the University of Iowa. It has a user-friendly interface and includes various tools such as posture prediction, reachability check, zone differentiation, and biomechanics assessment for the upper body and hand. In this paper, first introduced a human representation, then illustrated an assessment of a vehicle interior design.

Mathew P. Reed et al. [29] in their article presents a new approach for simulating the ingress and egress of a human figure model in to and out of vehicle using the human motion simulation Framework. The ease of getting into and out of passenger cars and light trucks (ingress and egress) is a critical component of customer acceptance and product differentiation in the contest of the health and safety of drivers and passengers.

Erika Baker et al. [16] in their article described the application of the Jack human model for the analysis of vehicle egress by military personnel following an accident. In post-accident situations, the vehicle attitude may prevent egress by the normal methods. This paper presents a case study of the application of the Jack DHM to analysis of egress from a vehicle following a rollover event. The paper concluded that the software was effective in documenting important clearance issues, but lacked the capability to automatically generate postures and motions.

Baekhee Lee et al. [3] in their article discussed the ergonomics analysis with Jack digital human by simulating the main control room of radioactive waste facility in South Korea. Four digital humanoids (5th, 50th, 95th, and 99th percentiles) were used in the ergonomic evaluation. A revised main control room design suggested in the present study would contribute to effective and safe operations of the main control room as well as operators health in the workplace.

A number of articles are published in the area of work system design with using digital human modeling. Lars Fritzsche et al. [25] in their paper investigated the advantages of ergonomics risk assessments with DHMs over real-life assessments obtained on a car assembly line. Two ergonomists evaluated 20 work tasks in real life and DHM simulation are done for assessing static postures, action forces, manual material handling, and extra strains. Results demonstrate that DHM simulations provide good estimations of the workload in real-life tasks.

Dan Lamkull et al. [9] in their article examining that, to what extent ergonomics simulations of manual assembly tasks correctly predict the real outcomes in the workstations. The results show that digital human modelling tools are useful for the purpose of providing designs for standing and unconstrained working postures. The study also identifies areas that require additional development in order to further improve the digital human modeling tools possibility to correctly predict a work tasks real outcome, i.e. hand access, push pressure and pull forces, leaning and balance behaviour and field of vision. Moreover, a better feedback of product and process changes and a more careful order description of simulation cases to the simulation engineers would lead to improved simulation results in current and future projects.

Christina Cort et al. [8] in their article highlights the uses of human simulation to solve a process re-design in the automotive components manufacturing sector. A process design concept involving manual materials handling was analyzed to quantify exposure to musculoskeletal stresses over the course of a work shift. Siemens Jack human Simulation assessment tools were successfully used to guide a re-design that reduced injury risk and improved process efficiency.

Fontes A. R. M. et al. [17] in their article the integration of digital human models and ergonomic analysis of work in a design process of a new workplace were discussed. Simulated static and dynamic tests are conducted by Delmia Human V5R18 (Dassaults Systems). The paper underlines that the use of digital human simulation to support workplace design is an important tool to anticipate the future work activity.

Sanjog et al. [33] in their article demonstrates virtual ergonomic evaluation of an ergonomic multi-purpose shoe rack for a small family with 5-6 members of varying age group to suit present day apartment model place of residence. A 3D-CAD model of shoe rack was designed and evaluated in DELMIA software with digital manikins representing Indian anthropometric data to justify the design for Indian users

Emilie Poirson et al. [14] in their article presented a comparison of digital human modeling software allowing performing a decision making tools to help the designer to choose his software. Twelve DHM software have been presented and compared, Viz. Jack (Siemens), Ramsis (Human Solutions), Catia (Dassault Systems), Santos (University of Iowa), Human Cad (Nexgen Ergonomics), 3DSSPP (University of Michigan), Poser (Smith Micro), Make Human (freeware), Anybody (Anybody Technology), Daz Studio (DAZ 3D Inc), Quidam (N-Sided), Sammie (Sammie CAD Ltd).

Wischniewski S. [40] in his article an expert- and web-based, three-round Delphi survey on ”Digital Ergonomics” was carried out. The paper presented the results of the Delphi survey gives an expert-based roadmap with short, middle and long-term trends in digital human modeling until 2025.

Sougata Karmakar et al. [37] in their article discussed the present scenario of application, research and development of DHM in India. Indian academic and research institutions along with various industries are using DHM and number of reported studies with the application of DHM technique has been investigated. But the DHM activities are still at its early stages of development as compared to developed countries, and only a few research publications are reported. The opportunities and difficulties of the broadly adoption of DHM in India are also highlighted.

Seung-kook Jun et al. [35] in their article give a detailed analyse of comparison between motion data from two alternate human motion-capture systems namely Vicon and Kinect, using the computational-analysis systems (AnyBody Modeling System/Visual-3D). The comparison results and characteristics of the whole systems are also presented in the article. The Vicon motion capture system uses high-speed (120Hz) digital cameras to track reflective markers placed over body segments (headneck, trunk, pelvis, arms, forearms, thighs and feet), from which 3D human movement is inferred using reconstructed 3D maker trajectories. The Kinect system consists of Kinect sensor interfaced sensors and the system can stream colour image, depth image data and also can recognize and track human skeleton joints.

The above papers mentioned the advantages and applications of DHM, The following papers list out the limitations and future of DHM. In most of the above mentioned papers, ergonomic analysis is conducted by considering only the static posture information which limits the capacity of ergonomics analysis. A dynamic DHM automatically controlled in force and acceleration will therefore be an important contribution to analysing ergonomic aspects, especially when it comes to movement, applied forces and joint torques evaluation. Such a DHM will fill the gap between measurements made on the operator performing the task and simulations made using a static DHM.

Giovanni De Magistris et al. [18] in an article introduced the principles of a new autonomous dynamic DHM, and described an application and validation case, based on an industrial assembly task adapted and implemented in the laboratory.

Don B. Chaffin [6] had proposed that future DHMs must include valid posture and motion prediction models for various populations, in order to improve the physical design of vehicle interiors or manufacturing workplaces. The article argued that existing posture and motion prediction models now used in DHMs must be based on real motion data to assure validity for complex dynamic task simulations. It is further proposed that if valid human posture and motion prediction models are developed, these can be combined with psychophysical and biomechanical models and it will be a very powerful tool for predicting dynamic human performance and population specific limitations.

Matthew P. Reed et al. [28] in their article presented a Human Motion Simulation (HUMOSIM) ergonomics framework to control the human models and to analyze the simulated tasks. HUMOSIM is a laboratory at the University of Michigan. This framework is developed for overcoming the limitations of existing DHM, such as time consuming manual manipulation of figures. The new approach consists of an interconnected, hierarchical set of postures and motions. Moreover issues such as shoulder stress and balance are integrated into the framework. A comprehensive system for motion simulation and ergonomic analysis is included in the framework. The HUMOSIM laboratory develops models to predict and evaluate realistic human movements. These models can be used by commercially available human computer aided design (CAD) software to enable ergonomic analysis of products and workplaces.

IV. CONCLUSION

DHM tools have improved significantly over the past decade. The promising area of application of DHMs is effective design and ergonomic analysis product and workstations (such as passenger car interior, fighter cockpit and industrial and manufacturing workstations). In this paper a review of the literatures related to use of DHMs is conducted in the perspective of ergonomics and is presented. The paper goes through the description of several research works according to the methodology or scientific approach they propose also the area or the sector they are concentrated. In the first part of the article traditional ergonomic analysing tools are discussed. In the continuing part the uses of DHMs are investigated in different areas such as product development, work system design and analysis. Some important references in this specific area are surveyed and discussed, highlighting modeling approaches, DHMs tools and analysis methodologies used etc. The limitations and futures of DHM tools based ergonomics are also discussed.

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