*International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)*
*Volume-2 Number-4 Issue-6 December-2012*

# Computer Aided Design in Digital Human Modeling for Human Computer Interaction in Ergonomic Assessment: A Review

**Suman Mukhopadhyay [1], Sanjib Kumar Das [2] and Tania Chakraborty [3]**
Assistant Professor[1] and Doctoral Fellows[2,3]
Ergonomics and Human Factors Engineering, National Institute of Industrial Engineering (NITIE), Mumbai, India 400087

## Abstract

***Research in Human-Computer Interaction (HCI) has been enormously successful in the area of computer-aided ergonomics or human-centric designs. Perfect fit for people has always been a target for product design. Designers traditionally used anthropometric dimensions for 3D product design which created a lot of fitting problems when dealing with the complexities of the human body shapes. Computer aided design (CAD), also known as Computer aided design and drafting (CADD) is the computer technology used for the design processing and design documentation. CAD has now been used extensively in many applications such as automotive, shipbuilding, aerospace industries, architectural and industrial designs, prosthetics, computer animation for special effects in movies, advertising and technical manuals. As a technology, digital human modeling (DHM) has rapidly emerged as a technology that creates, manipulates and control human representations and human-machine systems scenes on computers for interactive ergonomic design problem solving. DHM promises to profoundly change how products or systems are designed, how ergonomics analysis is performed, how disorders and impairments are assessed and how therapies and surgeries are conducted. The imperative and emerging need for the DHM appears to be consistent with the fact that the past decade has witnessed significant growth in both the software systems offering DHM capabilities as well as the corporate adapting the technology. The authors shall dwell at length and deliberate on how research in DHM has finally brought about an enhanced HCI, in the context of computer-aided ergonomics or human-centric design and discuss about future trends in this context.***

## Keywords

***Computer Aided Design, Digital Human Modeling, Human Computer Interaction, Ergonomics.***

## 1. Introduction and Background

Ergonomics (or human factors engineering) is a multidisciplinary science concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

Ergonomists are concerned with the 'fit' between the user, equipment and their environments. It takes account of the user's capabilities and limitations in seeking to ensure that tasks, functions, information and the environment suit each user.

To assess the fit between a person and the used technology, ergonomists consider the job (activity) being done and the demands on the user; the equipment used (its size, shape, and how appropriate it is for the task), and the information used (how it is presented, accessed, and changed). Ergonomics draws on many disciplines in its study of humans and their environments, including anthropometry, biomechanics, mechanical engineering, industrial engineering, industrial design, information design, kinesiology, physiology and psychology.

The foundations of the science of ergonomics appear to have been laid within the context of the culture of Ancient Greece, who, as early as in the 5th century BC used ergonomic principles in the design of their tools, jobs, and workplaces. One outstanding example of this can be found in the description Hippocrates gave of how a surgeon's workplace should be designed and how the tools he uses should be arranged. It is also true that archaeological records of the early Egyptians Dynasties made tools, household equipment, among others that illustrated ergonomic principles. The term ergonomics derives from Greek Έργον, meaning "work", and Νόμος, meaning "natural laws", coined by Wojciech Jastrzębowski in 1857.

Later, in the 19th century, Frederick Winslow Taylor pioneered a method for optimizing carrying tasks which resulted in tripling the amount of coal that workers were shoveling by incrementally reducing the size and weight of coal shovels until the fastest shoveling rate was reached. Frank and Lillian Gilbreth expanded Taylor's methods in the early 1900s to develop "Time and Motion Studies", which aimed at improving efficiency by eliminating unnecessary and useless steps and actions. They were thus able to reduce the number of motions in bricklaying from 18 to 4.5, allowing bricklayers to increase their productivity from 120 to 350 bricks per hour.

World War II marked the development of new and complex machines and weaponry, and these made new demands on operators' cognition. The decision-making, attention, situational awareness and hand-eye coordination of the machine's operator became important in the success or failure of a task.

In the decades since the war, ergonomics has continued to flourish and diversify. The dawn of the information age has resulted in the new ergonomics field of human-computer interaction (HCI). Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomenon surrounding them.From a computer science perspective, the focus is specifically on interaction between one or more humans and one or more computational machines.

With the development of computer technology and change of the demands, ergonomics has received greater assistance from computer-related technologies over the last two decades. This situation expedites the development of Computer-Aided Ergonomics & Safety (CAES). As pointed out by Feyen, Liu, Chaffin, Jimmerson, and Joseph (2000), ergonomists can use computer-aided techniques to evaluate the performance of human operators in a workplace design which allow ergonomic information from several sources to be examined before an actual job is implemented.

As a technology, digital human modeling (DHM) which has always been at the forefront of ergonomic research, is being propelled at an unprecedented tempo in the digital age by the advancement of computer technology. DHM is a means to create, manipulate, and control human representations and human –machine system scenes on computers for interactive ergonomics and design problem solving. Digital human modeling (DHM) and virtual human simulation (e.g., 3DSSPP, EAI Jack, RAMSIS) have been created to facilitate ergonomic evaluations (Ma et al., 2009a) [47].

## 2. HCI in Ergonomic assessment: Historical Perspectives to Recent Trends

Human Computer interaction studies a human and a machine in communication; it draws from supporting knowledge on both the machine and the human side. On the machine side, techniques in computer graphics, operating systems, programming languages and development environments are relevant. On the human side, communication theory, graphic and industrial design disciplines, linguistics, social sciences, cognitive psychology, and human performance and of course, engineering and design methods are relevant.
Research in HCI has been spectacularly successful and has fundamentally changed computing. Out of the line of development came a number of important building blocks for human-computer interaction. Some of these building blocks include the mouse, bitmapped displays, personal computers, windows, the desktop metaphor and point and click editors (Baecker and Buxton, 1987, Chapter1). With the computing power and computational methods available today, we are able to render digital human models that are an order of magnitude more sophisticated and realistic than the ones produced a decade ago. There is however still a long way to go before we achieve the “ultimate” digital human surrogates-ones that look, act and even think like we do.

A research by Gert Zulch,Tim Grieger, 2005[26], states that entire factories along with their production facilities can be recreated realistically in a computer model in which the running processes can be simulated. ADAMO, a tool allowing Occupation Health and Safety data to be prognosticated and documented in a virtual representation of a work system and for this to be used in the prognosis of stress situations, has been created. The advanced development in these areas of HCI and due to the fact that well-known companies are fostering its development, the existing approaches will much more enhance in coming era.

A deeper analysis would reveal much interaction between the university, corporate research and commercial activity streams. It is important to appreciate that years of research are involved in creating and making these technologies ready for widespread use. The same will be true for the HCI technologies that will provide the interfaces of tomorrow.

## 3. DHM in HCI for enhanced Ergonomic Assessment

DHM is rapidly emerging as an enabling technology, with the promise to profoundly change how products or systems are designed, how ergonomic analyses are performed, how disorders and impairments are assessed and how therapies and surgeries are conducted. Digital human representation in various forms are increasingly been incorporated in CAD of human machine-systems, like driver vehicle system or a manufacturing workstation. Some DHM tools can calculate the biomechanical attributes (e.g., Anybody R Modeling System, 3DSSPP™) and predict physical fatigue and potential disorder risk. These analytical tools can be used to identify and mitigate ergonomic problems of a designed product, workstation, or job in order to promote human considerations and protect the users, during an early stage of design.

**Research approaches**

Digital human model (DHM) simulation systems such as Jack R and RAMSIS R contribute to the efficiency of product design process. These systems have been utilized as an effective design tool to visualize the interaction of a human and workstation system (such as passenger car interior, fighter cockpit, and factory workplace) and to evaluate the human–workstation interaction from ergonomic aspects (such as reach, visibility and comfort). The ergonomic design methodology using digital DHMs makes the iterative process of design evaluation, diagnosis and revision more rapid and economical (Chaffin, 2001) [12]. Two human model generation methods (percentile and custom-built methods) are commonly implemented in DHM simulation systems (Dassault Systems, 2005; UGS, 2006). The study by Kihyo Jung , Ochae Kwon , Heecheon You, 2009[39] proposed a novel method to generate a group of human models with various sizes which statistically represent the target population and the study implemented the proposed method into a web-based system, which automatically generates a group of human models as nationality, gender, accommodation range (the range of percentiles accommodated by a particular design) of the target population, and the number of human models required are specified.

Digital human modeling is very useful in the areas of customized product design, multimedia games, and virtual reality (Kuo and Wang, 2009) [41]. Once the 3D human model is constructed, the dig-ital human can be visualized and animated. With the advancement of optoelectronic technology, the 3D human model can be constructed by using 3D whole body scanner. The 3D whole body scanning system has been used in several national anthropometric surveys, such as the Civilian American and European Surface Anthropometry Resource (CAESAR) Project for establishing the anthropometric database (Robinette, Daanen, and Paquet, 1999) [62]. The obtained 3D scanning human models can be used for various applications including proactive product design and workplace evaluations (Lu and Wang, 2008) [43]. However, the use of 3D scanner for constructing 3D human model is very costly, and lacking of mobility (Seo, Yeo, and Wohn, 2006) [65]. A low-cost system for constructing 3D human model is therefore needed. Yueh-Ling Lin, Mao-Jiun J. Wang, 2012 [74] thus proposed a 3D human model construction system using the feature information from the front and side 2D images of a person. The integrated system involves feature extraction, body shape deformation and 3D model construction. After taking 2D photographs, a body feature extraction algorithm was developed to obtain feature points and collect body dimensions. Based on the obtained body dimensions, a 3D template human model was identified for body shape deformation and thus, a customized 3D human model was constructed.

The idea of simulating the human motion during the study of human functionality in working environments, aiming at designing for ergonomics (Badler et al., 1992) [3], has been approached by many researchers in recent years. A system mostly performing human body animation has been developed (Boulic et al., 1997 )[5], while more recently, some geometric inverse kinematics algorithms, which integrate the observed human movement strategies, have been proposed (Wang, 1999) [68]. Researchers, in the ANNIE project, trained a neural network to perform arm movement simulation without involving in their work the entire body (Rigotti et al., 2001) [58]. Other recent approaches to motion simulation utilize a database of movements for human motion modeling and prediction (Park et al., 2002[54]; Wang, 2002[69]). In the field of human motion analysis and modeling, statistical analysis of human motion capture data has been performed in many published works , such as Porter et al. (1990) [56], Das and Sengupta (1995) [17] , Zhang and Chaffin (1996) [76] , Das and Behara (1998)[18], Far away et al. (1999)[24] and Faraway (2000) [23] .

Some of the results deriving from these studies have been embedded in commercial human simulation software tools, such as Jack (UGS website, 2005), Safework (Safework web site, 2005) and Ramsis (Ramsis website, 2005). As Zhang and Chaffin (2005) [78] described, the core of digital human modeling (DHM) and simulation is a model – a biomechanical representation of a human body along with the computational algorithms that configure or drive the representation to produce postures or motions. Despite many benefits achieved from DHM, including easier and earlier identification of ergonomics problems, lessening or sometimes even eliminating the need for physical mock-ups and real human participant testing, and proactive ergonomics analysis (Badler, Phillips, and Webber, 1992[3];Morrissey, 1998 [51]; Porter, Case and Freer, 1999 [57]; Zhang and Chaffin 2000), Chaffin (2001) pointed out the insufficient ability of existing DHM to predict position, posture and motion of a person in most task conditions. Since considering only static posture information limits the capacity of ergonomics analysis, so, Renran Tian, Vincent G. Duffy, 2011 [60] proposed in their study, the methodology of performing dynamic ergonomics analysis based on Virtual Interactive Design platform.

**Virtual Interactive Design methodology**

Virtual Interactive Design (VID) is introduced by Li, Duffy and Zheng (2006) [42] to examine seated reaching behavior for accessing an ATM under limited mobility task conditions. Different from previous studies which rely on computational algorithms to drive or configure the kinematical human model, VID focuses on integrating motion capture systems (MOCAP) with the visualization part of DHM to allow the DHM driven by actual human motions. By connecting the DHM with different static ergonomics analysis tools, this method enables real-time ergonomic analysis to justify modifications to human–machine interface designs. Wu, Tian, and Duffy (2011) have examined the validity and reliability of sta-tic VID methodology by comparing VID output which is based on MOCAP with traditional DHM-based ergonomics analysis results, and they concluded that static VID is valid and reliable in many cases. Du and Duffy (2007) [21] applied the static VID in industry to assess workstation redesign.

This environment allows velocity and angular velocity of specified body segments/joints calculated for designed tasks to be used to assess the corresponding risk levels based on Job Risk Classification Model. The motion calculation is completed based on the captured interaction between human participants and virtual workplace/mockup. In current VID system, no feedback other than visual feedback has been applied in VE which results in an increased error for using VID for higher complexity tasks. Appropriate feedback methods can be investigated, especially force feedback with moderate physical boundary involved (Demirel and Duffy, 2009) [20]. Another direction to improve VID environment is to further study the DHM motion calculation algorithm in coming future.

Recent progresses in information technologies provide many useful tools for accomplishing human-centric design. A number of software tools (M. Launis, J. Lehtela 1992 [46], J.W. McDaniel-1990 [37], R. Lin, J.G. Kreifeldt 2001[63], N. Corlett, T.S. Clark 1995 [52], J. Laring et al 1996 [38]) have been developed for ergonomic design of consumer pro-ducts, machines, workplaces, and occupational devices. Most of them utilize full-scale CAD systems and/or high-end virtual reality environment for ergonomic estimation (A. Seidl 1997[1], J.A. Westerink et al 1990[32]). However, CAD or VR tools may not be always available to product designers or small/medium enterprises that cannot afford such costly tools. In addition, any ergonomic evaluation for consumer products should be conducted based on appropriate anthropometry data. It is not very likely that anthropometry databases and design tools are located in one software system within a company, and thus, the integration between them poses a serious problem. Very little research has addressed this issue. A research by Chien-Fu Kuo, Chih-Hsing Chu, 2005[14] is the first study that realizes the web-based ergonomic evaluation for 3D car interior design with no needs of high-end CAD systems or complex VR environment. This study develops a web-based light-weighted ergonomic evaluator for vehicle interior design. A digital human model is constructed based on Taiwan local anthropometry data that enables the user to query ergonomic information through a regular browser. The product model is simplified from its original 3D CAD representation, but still retains necessary information for the purpose of ergonomic evaluation. This system allows the 3D human to interact with the product model, thus mimicking the condition in which a person is sitting in the front seat and driving the vehicle. Given a posture, physical loads on the body joints of the digital human can be computed using the Chaffin's biomechanical model. In this manner, the user can interactively adjust the interior setting until a better design is obtained that gives a more comfortable posture explicitly for the user. This work demonstrates the feasibility of web-based ergo centric product design with no needs of CAD or VR systems. It provides both the designer and end-customer (M. Baxter 1995 [45]) an easy but effective solution for ergonomic evaluation of product development at the early design stage.

## 4. Conclusion and Future Trends

Contemporary research shows that ergonomic analyses based on human motion generate more accurate results than those solely based on postures. Without consideration for the dynamic aspects of task, in addition to initial and final positions that give information about static aspect, potential risk may be underestimated by as much as 40% (Feyen et al., 2000) [25]. Thus, using captured human motions as the source to drive the virtual interaction between digital human manikin and virtual work environment, and applying dynamic ergonomics analysis models like Job Risk Classification Model based on the motions achieved from such a virtual interaction, provide a promising way to further improve current CAES systems.

Musculoskeletal Disorders is believed to be closely related to posture, physical over-exertion, duration and frequency of physical effort, discomfort, and physical fatigue (Pheasant, 1999) [55]. In order to reduce MSD risks, many methods have been developed to investigate ergonomic design problems. The Ovako Working Posture Analysis System (OWAS) was designed to facilitate the evaluation of the overall human body (Scott and Lambe, 1996) [64]. The posture targeting method (Corlett et al., 1979) [15] and Rapid Entire Body Assessment (REBA) (Hignett and McAtamney, 2000)[30] were also designed to evaluate total body postures, while Rapid Upper Limb Assessment (RULA) was specially designed to evaluate upper body postures (McAtamney and Corlett, 1993[48]; Bao et al., 2007 [4]). However, in these conventional methods, evaluation must be conducted in the field, which requires a great deal of effort and an expensive physical mock-up.

The currently popular 3D ergonomics aided design software, for example, Safework, Jack, and RAMSIS, support posture modeling based typically on regression analysis and statistical models (Hoekstra, 1997 [31]; Chaffin, 2001 [12]; Lamkull et al., 2009 [44]). However recent trend of studies seen on artificial neural networks based on the principles of back-propagation feed -forward network is in progress which may solve the problems related to (a) the time needed to measure the human body in every posture, and (b) the storage of the data obtained in extreme large number of measurements, (B. Zhang et al 2010) [2].

Despite the positive results of these studies, certain limitations are still evident and need to be addressed, for instance, the models presented, can be applied only to a specific model. However, observing the experimental videos it is easily understandable that apart from anthropometrics, also environmental parameters influence the human motion paths (D. Mavrikios et al 2006) [16]. However HCI as a field is continuing to develop rapidly. Future work on VID research and further study of the DHM motion calculation algorithm would investigate the higher complexity tasks. New paradigms will emerge as our fundamental concepts evolve, becomes more clearly articulated and spin off entirely new subtopics.

## References

[1] A. Seidl, RAMSIS: A New CAD-tool for Ergonomic Analysis of Vehicles Developed for the German Automotive Industry, vol. 1233, Automotive Concurrent/Simultaneous Engineering SAE Special Publications, 1997, pp. 51–57.

[2] B. Zhang, I. Horváth, J.F.M. Molenbroek , C. Snijders: Using artificial neural network s for human body posture prediction, International Journal of Industrial Ergonomics 40 (2010) 414-424.

[3] Badler, N.I., Phillips, C.B., Webber, B.L., 1992. Simulating Humans: computer Graphics Animation and Control. Oxford University Press, Oxford.

[4] Bao, S., Howard, N., Spielholz, P., Silverstein, B., 20 07. Two posture analysis approaches and their application in a modi fied rapid upper limb assessment evaluation. Ergonomics 50 (12), 2118-2136.

[5] Boulic, R., Becheiraz, P., Emeric, L., Thalmann, D., 1997. Integration of motion control techniques for virtual human and avatar real-time animation. ACM International Symposium VRST, 111–118.

[6] Bittner, A.C., 2000. A-CADRE: Advanced family of manikins for workstation design. In: Proceedings of the IEA 2000/HFES 2000 Congress. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 774-777.

[7] Bo Hu, Liang Ma, Wei Zhang, Gavriel Salvendy, Damien Chablat, Fouad Bennis: Pred icting real-world ergonomic measurements by simulation in a virtual environment, International Journal of Industrial Ergonomics 41 (2011) 6 471.

[8] Bridger, R.S., 1991. Some fundamental aspects of posture related to ergonomics. International Journal of Industrial Ergonomics 8, 3 -15.

[9] Buck, M., 1998. Immersive user interaction within industrial virtual environment. In: Virtual Reality for Industrial Applications. Springer-Verlag, Berlin, pp. 39 - 60.
[10] Buckle, P., Devereux, J., 1999. Work Related Neck and Upper Limb Musculoskeletal Disorders. European Agency for Safety and Health at Work, Luxembourg, pp. 7 -8.
[11] Chaffin, D.B., Erig, M., 1991. Three-dimensional biomechanical static strength prediction model sensitivity to postural and anthropometric inaccuracies. IIE Transactions 23 (3), 215 -227.
[12] Chaffin, D.B., Nelson, C., Ianni, J.D., 2001. Digital human modeling for vehicle and workplace design. SAE International, 82 - 87.
[13] Chaffin, D.B., Faraway, J.J., 2000. Stature, age and gender effects on reach motion postures. Human Factors 42 (3), 408–420.
[14] Chien-Fu Kuo, Chih-Hsing Chu: An online ergonomic evaluator for 3D product design, Computers in Industry 56 (2005) 479–492.
[15] Corlett, E.N., Madeley, S.J., Manenica, I., 1979. Posture targeting: a technique for recording working postures. Ergonomics 22 (3), 357 e366.
[16] D. Mavrikios, V. Karabatsou, K. Alexopoulos, M. Pappas, P. Gogos, G. Chryssolouris: An approach to human motion analysis and modeling, International Journal of Industrial Ergonomics 36 (2006) 979 – 989.
[17] Das, B., Sengupta, A.K., 1995. Computer-aided human modeling programs for workstation design. Ergonomics 38, 1958–1972.
[18] Das, B., Behara, D.N., 1998. Three-dimensional workspace for industrial workstations. Human Factors 40 (4), 633–646.
[19] Delmia. Quest: The Systems Integration, Process Flow Design and Visualization Solution 2004. (Internet: http://www.del-mia.com, 04.02.2004).
[20] Demirel, H. O., & Duffy, V.G. (2009). Impact of force feedback on computer aided ergonomics analyses. In Proceedings of HCI international, San Diego, July.
[21] Du, C. J., & Duffy, V. G. (2007). Development of a methodology for assessing industrial workstations using optical motion capture integrated with digital human models. Occupational Ergonomics, 7(1), 11–25.
[22] Eynard, E., Fubini, E., Masali, M., Cerrone, M., Tarzia, A., 2000. Generation of virtual man models representative of different body proportion and application to ergonomic design of vehicles. In: Proceedings of the IEA2000/HFES2000 Congress. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 489-492.
[23] Faraway, J.,2000. Modeling reach motions using functional regression analysis. SAE Technical Paper 2000, 2000-01-2175.
[24] Faraway, J., Zhang, X., Chaffin, D., 1999. Rectifying postures reconstructed from joint angles to meet constraints. Journal of Biomechanics 32, 733–736.
[25] Feyen, R., Liu, Y., Chaffin, D. B., Jimmerson, G., & Joseph, B. (2000). Computer-aided ergonomics: A case study of incorporating ergonomics analyses into workplace design. Applied Ergonomics, 31, 291–300.
[26] Gert Zulch, Tim Grieger: Modelling of occupational health and safety aspects in the Digital Factory, Computers in Industry 56(2005) 384–392.
[27] HFES300, 2004. Guidelines for Using Anthropometric Data in Product Design. Human Factors and Ergonomics Society, Santa Monica, CA.
[28] Haslegrave, C.M., 1994. What do we mean by a working posture? Ergonomics 37, 781 -799.
[29] Hedge, A ., Morimoto, S., Mccrobie, D., 1999. Effects of keyboard tray geometry on upper body posture and comfort. Ergonomics 42 (10), 1333 - 1349.
[30] Hignett, S., McAtamney, L., 2000. Rapid entire body assessment (REBA). Applied Ergonomics 31 (2), 201 -205.
[31] Hoekstra, P.N., 1997. 3D-Surface anthropometry of functional posture. In: Seppala, P. , Luopajarvi, T., Nygard, C.H., Mattila, M. (Eds.), From Experience to Innovation-IEA'97. Proceedings of the 13th Triennial Congress of the Interna-tional Ergonomics Association, Tampere, Finland, June 29 e July 4, 1997. Finnish Institute of Occupational Health, Helsinki, pp. 358- 360.
[32] J.A. Westerink, H. Tragter, A. Van Der Star, D.P. Rookmaaker, TADAPS: a three-dimensional CAD man model, in: W. Kar-kowski, A.M. Genaidy, S.S. Asfour (Eds.), Computer-Aided Ergonomics, Taylor & Francis, London, 1990, pp. 90–103.
[33] Jayaram, U., Jayaram, S., Shaikh, I., Kim, Y., Palmer, C., 2006. Introducing quantitative analysis methods into virtual environments for real-time and continuous ergonomic evaluations. Computers in Industry 57 (3), 283 - 296.
[34] Jimmerson, D.G., 2001. Digital human modeling for improved product and process feasibility studies. In: Chaffin, D.B. (Ed.), Digital Human Modeling for Vehicle and Workplace Design. SAE International, Warrendale, PA, pp. 127–135.
[35] Jung, K., You, H., Kwon, O., 2008. A multivariate evaluation method for representative human model generation methods: application to grid method. In: Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 1665–1669.
[36] Jung, K.H., Kwon, O., You, H.C., 2009. Development of a digital human model generation method for ergonomic design in virtual environment. International Journal of Industrial Ergonomics 39, 74 4-748.

[37] J.W. McDaniel, Models for ergonomic analysis and design: COMBIMAN and CREW CHIEF, in: W. Karkowski, A.M Genaidy, S.S. Asfour (Eds.), Computer-Aided Ergonomics, Taylor & Francis, London, 1990, pp. 138–156.

[38] J. Laring, K.J. Falk, R. Kadefors, R. Ortengren, Computer aided workplace design: an approach to create a tool for the production engineer, International Journal of Industrial Ergo-nomics 17 (4) (1996) 323–330.

[39] Kihyo Jung , Ochae Kwon , Heecheon You: Development of a digital human model generation method for ergonomic design in virtual environment, International Journal of Industrial Ergonomics 39 (2009) 744–748.

[40] Kim, J., Whang, M., 1997. Development of a set of Korean manikins. Applied Ergonomics 28 (5), 407–410.

[41] Kuo, C. F., & Wang, M. J. (2009). Motion generation from MTM semantics. Computers in Industry, 60, 339–348.

[42] Li, K., Duffy, V. G., & Zheng, L. (2006). Universal accessibility assessments through virtual interactive design. International Journal of Human Factors Modeling and Simulation, 1(1), 52–68.

[43] Lu, J. M., & Wang, M. J. (2008). Automated data collection using 3D whole body scanner. Expert Systems with Applications, 35, 407–414.

[44] Lamkull, D., Hanson, L., Ortengren, R., 2009. A comparative study of digital human modeling simulation results and their outcomes in reality: a case study within manual assembly of automobiles. International Journal of Industrial Ergonomics 39, 428 - 441.

[45] M. Baxter, Product Design, Chapman & Hall Publication, London, 1995.

[46] M. Launis, J. Lehtela, Ergo SHAPE: a design oriented ergonomic tool for AutoCAD, in: M. Mattila, W. Karkowski (Eds.), Computer Applications in Ergonomics, Occupational Safety, and Health, Elsevier, 1992, pp. 121–128.

[47] Ma, L., Chablat, D., Bennis, F., Zhang, W., 2009a. A new simple dynamic fatigue muscle model and its validation. International Journal of Industrial Ergonomics 39 (1), 211 -220.

[48] McAtamney, L., Corlett, E.N., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Applied Ergonomics 24 (2), 91 -99.

[49] McCulloch, C.E., Paal, B., Ashdown, S.P., 1998. An optimization approach to apparel sizing. Journal of the Operational Research Society 49 (5), 299–492.

[50] Meindl, R.S., Hudson, J.A., Zehner, G.F., 1993. A Multivariate Anthropometric Method for Crew Station Design (AL-TR-1993-0054). Armstrong Laboratory, Wright-Patterson.

[51] Morrissey,M.(1998).Human-centric-design. Mechanical Engineering, 120(7), 60–62.

[52] N. Corlett, T.S. Clark, The Ergonomics of Workspaces and Machines: A Design Manual, Taylor and Francis, London, 1995.

[53] Nelson, C., 2001. Anthropometric analyses of crew interfaces and component accessi-bility for the international space station. In: Chaffin, D.B. (Ed.), Digital Human Modeling for Vehicle and Workplace Design. SAE International, Warrendale, PA, pp. 17–36.

[54] Park, W., Chaffin, D.B., Martin, B.J., 2002. Memory–based motion simulation. Proceeding of the 5th SAE Digital Human Modelling Conference, 255–270.

[55] Pheasant, S., 1999. Body Space: Anthropometry, Ergonomics and the Design of Work. Taylor & Francis, Philadelphia, pp. 121-123.

[56] Porter, J.M., Case, K., Bonney, M.C., 1990. Computer workspace modelling. In: Wilson, J.R., Corlett, E.N. (Eds.), Evaluation of Human Work. Taylor & Francis, London, UK, pp. 472–499.

[57] Porter, J. M., Case, K., & Freer, M. T. (1999). Computer-aided design and human models. In W. Karwowski & W. S. Marras (Eds.), the occupational ergonomics handbook (pp. 479–500). Boca Raton: CRC Press.

[58] Rigotti, C., Cerveti, P., Andreoni, G., Pedotti, A., Ferrigno, G., 2001. Modelling and driving a reduced human mannequin through motion captured data: A neutral network approach. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans 31 (3), 187–193.

[59] Reed, M.P., Flannagan, C.A.C., 2000. Anthropometric and postural variability: limitations of the boundary manikin approach. SAE Transactions: Journal of Passenger Cars Mechanical Systems 109, 2247–2252. Technical Paper No. 2000-01-2172.

[60] Renran Tian, Vincent G. Duffy: Computerized task risk assessment using digital human modeling based Job Risk Classification Model, Computers & Industrial Engineering 61 (2011) 1044–1052.

[61] Robinette, K.M., Vannier, M.W., Rioux, M., Jones, P.R.M., 1997. AGARD Advisory Report 329: 3 e D Surface Anthropometry: Review of Technologies. Advisory Group for Aerospace Research & Development, 7 Rue Ancelle, 9220 0 Neuilly-Sur-Seine, France.

[62] Robinette, K.M., Daanen, H., & Paquet, E., 1999. The Caesar project: A 3D surface anthropometry survey. In Proceedings of the Second international conference on 3D digital imaging and modeling, pp. 380–386.

[63] R. Lin, J.G. Kreifeldt, Ergonomics in wearable computer design, International Journal of Industrial Ergonomics 27 (4) (2001) 259–269.

[64] Scott, G.B., Lambe, N.R., 1996. Working practices in a perchery system, using the OVAKO working posture analysing system (OWAS). Applied Ergonomics 27 (4), 281 -284.

[65] Seo, H., Yeo, Y., & Wohn, K. (2006). 3D body reconstruction from photos based on range scan. Lecture Notes in Computer Science, 3942, 849–860.
[66] Thompson, D.D., 2001. The determination of the human factors/occupant packaging requirements for adjustable pedal systems. In: Chaffin, D.B. (Ed.), Digital Human Modeling for Vehicle and Workplace Design. SAE International, Warrendale, PA, pp. 101–11.
[67] S., Ojanen, K., Pyykkonen, M., Peuraniemi, A ., Suumakkil, T., Kemppainen, M., 1990. In: Karwowski, W., Genaidy, A .M., Asfour, S.S. (Eds.), OWASCA: Computer-Aided Visualizing and Training Sof tware for Work Posture Analysis. Taylor & Francis, London, pp. 273- 278.
[68] Wang, X., 1999. A behaviour-based inverse kinematics algorithm to predict arm prehension postures for computer aided ergonomic evaluation. Journal of Biomechanics 32, 453–460.
[69] Wang, X., 2002. Prediction of lower-limb movements of clutch pedal operation from an existing motion database. Proceeding of the 5th SAE Digital Human Modelling Conference, 271–283.
[70] Wang, Y., Liao, K., Guo, Y., Zhang, Y., Zhang, W., Wu, S., 2007. Development and application of integrated human machine interaction simulation system. Journal of System Simulation 19 (11), 24 92 -2495.
[71] Whitman, L., Jorgensen, M., Hathiyari, K., Malzahn, D., 2004. Virtual reality: its usefulness for ergonomic analysis. In: Proc. of the 20 04 Winter Simulation Conference, Washington, D.C., pp. 1745.
[72] Wier, A ., Lee, J.H., Spencer, S., 1991. Human Fit-the next generation anthropometric tool for designers. In: Proceedings of Interface 91': the 7th Symposium on Human Factors and Industrial Design in Consumer Products. Consumer Products Technical Group of the Human Factors Society.
[73] Wu, T., Tian, R., & Duffy, V. G. (2011). Performing ergonomics analyses through virtual interactive design: Validity and reliability assessment. Human Factors and Ergonomics in Manufacturing & Service Industries.. doi:10.1002/hfm.20267.
[74] Yueh-Ling Lin, Mao-Jiun J. Wang: Constructing 3D human model from front and side images, Expert Systems with Applications 39 (2012) 5012–5018.
[75] You, H., Oesterling, B., Bucciaglia, J., Lowe, B.D., Gilmore, B.J., Freivalds, A., 1997. Bus Operator Workstation Evaluation and Design Guidelines: Summary. National Academy Press, Washington, DC.
[76] Zhang, X., Chaffin, D.B., 1996. Task effects on three-dimensional dynamic postures during seated reaching movements: an Analysis method and illustration. Proceedings of the 40th Annual Meeting of the Human Factors and Ergonomics Society, 594–598.
[77] Zhang, X., & Chaffin, D. B. (2000). A three-dimensional dynamic posture prediction model for simulating in-vehicle seated reaching movements: Development and validation. Ergonomics, 43, 1314–1330.
[78] Zhang, X., & Chaffin, D. B. (2005). Digital human modeling for computer-aided ergonomics.

**Dr. Suman Mukhopadhyay** (Date of Birth: 28th May, 1966) is an Assistant Professor in the Dept. of Ergonomics and Human Factors Engineering, in NITIE, Mumbai, India. He has a vast experience of more than 20 years in teaching, research and providing scientific back up. He is also an accredited Sports and Exercise Physiologist and is a visiting Cardiopulmonary Physiologist at Shushrusha Citizens' Co-operative Hospital, Mumbai. He had worked at the National Institute of Sports, Patiala for 14 years (from 1992-2006), provided scientific backup and support to national athletes of Asian Games, Commonwealth Games and Olympics. He was Head of the Department of Sports and Exercise Physiology from June 1996 to June 1997 and October 2002 to May 2006. He has authored chapters in several books, guided several PhD thesis and Masters level dissertation projects.

**Sanjib Kumar Das**, born in 1983, is presently a Fellow (Doctoral) Scholar in National Institute of Industrial Engineering, Mumbai, India under Ministry of HRD, Govt. of India. He is a qualified physiotherapist, graduated from Institute of Post Graduate Medical Education and Research Centre (under Calcutta University) and trained from SSKM Hospital (under Govt. of West Bengal, India). He specializes in Musculoskeletal Disorders. He is also a consultant, an examiner and paper setter under W.B University of Health Sciences, India.

**Tania Chakraborty** is presently a Fellow (Doctoral) Scholar in National Institute of Industrial Engineering, under Ministry of HRD, Govt. of India. She graduated and post graduated in Physiology from Calcutta University, India. She has published her works in national and international journals of repute. She has also co-authored a chapter in Developments in Agricultural and Industrial Ergonomics, Vol II, Allied Publishers Pvt Ltd.