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Digital human modelling and the ageing workforce

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Abstract

Digital human modelling (DHM) has often focused on user populations that could be characterised as able-bodied and in the working age group. It is clear however that demographic changes are resulting in older populations in developed countries but this is also becoming increasingly true even in developing countries. The economic pressures of increased life expectancy are resulting in demands for workers to remain in employment well past what would previously have been considered a normal retirement age. In many countries legislation is increasing retirement ages for entitlement to state pensions, and enforceable retirement ages are being outlawed. As a consequence older working populations can be expected. Age in the workforce has many positive aspects including increased experience, wisdom, loyalty and motivation, but an inevitable consequence of ageing is negative effects such as the loss of capabilities in strength, mobility, vision and hearing. The challenge of including older workers is recognised as an important aspect of Inclusive Design and DHM is recognised as a potentially useful method for its implementation. Today's highly demanding and competitive working environments require the highest levels of productivity from individuals so that overall operational and business objectives can be achieved. DHM-based workplace risk assessment methods have successfully been used to improve working environments by conducting virtual posture based ergonomic risk analysis. Older workers are significantly different from younger workers in terms of their physical, physiological and cognitive capabilities and these capabilities directly or indirectly affect human work performance. This article suggests the use of human capability data in a virtual environment to explore the level of acceptability of a working strategy based on real capability data (joint mobility in this case) of older workers. A case study shows that the proposed DHM-based inclusive design method is useful recommending working strategies that are acceptable for older workers in terms of work productivity, well-being and safety.

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1. Introduction

This article discusses global workforce challenges and focuses on changing demographic trends in terms of workforce diversity and ageing. Humans differ in many aspects and age significantly affects human capabilities that influence work performing capabilities. Consequently there is a need for design methodologies that can address the needs of older people while they are working. A proposed digital human modeling based inclusive design methodology is introduced and verified by conducting a case study in a furniture manufacturing company.

2. Background literature

Diversity refers to differences between individuals because of their gender, age, functional capability, cultural background, experience and education [1]. There are multiple dimensions of diversity but age, race, gender, disability and national origin are frequently considered [2]. Workforce diversity comes with a number of potential benefits and challenges as it increases work performance inconsistencies because of human variability issues. Effective diversity management can provide an opportunity for better work performance by utilizing more diverse ideas in decision making. However, failure to manage a diverse workforce may lead to an environment of conflicts, frustration and sense of insecurity that can promote absenteeism, high turnover, job dissatisfaction and lower work commitment [2, 3]. However, competitive advantages arise from having a diverse workforce, such as variations in skills, experiences and backgrounds that can increase creativity, competitiveness and innovation [3-5].

The focus of this research is on age as a major dimension of diversity. The world is experiencing a significant increase in the proportion of older people. There were about 759 million people aged 60 or above in 2010, but it is estimated that this will increase to 2 billion by 2050, with this trend being more prominent in the developing world. It is estimated that one out of 5 persons will be of age 60 years or above by 2050 and this will significantly increase the dependency ratio (the proportion of economically inactive versus active population).

Like other parts of the world, the UK population is also ageing [6]. There has been an increase of 1.7 million people aged 65 and over in last 25 years. On the other hand, the percentage of the population aged less than 16 years has decreased from 21 percent to 19 percent from 1984 to 2009. The continuing trend by 2030 will result in the percentage of people aged more than 65 years being approximately 23 percent, whereas the percentage of the population under 16 years will further decrease to 18 percent. There are other noticeable trends in the UK population which will continue in the future. These are that the fastest percentage increase in the population will be in those who are more than 85 years old and a decrease in the ratio of women to men in the over-65 age group. In comparison with other European countries the UK has a relatively higher birth rate, which makes it these considerations less alarming than they are elsewhere.

These demographics in the context of the recent global economic crisis encourage the retention of older and experienced workers, so that this resource might be utilized for national and global economic growth. This is reflected in recent UK legislation removing compulsory retirement ages and increasing the age for receipt of state pensions. However, retention of older workers comes with potential benefits and challenges for the organizations. Experience, knowledge and skills of older workers are considered prominent factors that attract positive inclination of employers and older workers are considered as an asset for the organization. However, decline in physical and physiological capabilities, and differences in psychological attitudes and behaviour create many challenges. There is a need to understand the effects of ageing and the potential impact on work performance. A realistic understanding of both positives and negatives about older workers can provide an opportunity for designers to address the design needs of this part of the workforce. Otherwise, unrealistic and over ambitious production targets create a mismatch between job demands and working capabilities of older workers. Such situations ultimately result in an unsatisfied, over-stressed, frustrated and less loyal workforce and a decrease in individual and organizational work performance.

Age affects humans in different ways including the physical, physiological, cognitive, psychological, attitudinal and psychosocial aspects. There is a need to understand all these changes so that the challenges faced by older workers might be addressed in a logical way. However, physical, physiological and cognitive issues are the primary concern for designers, ergonomists, managers, engineers and human resources personnel.

The functional capacity of workers declines with age in a number of ways and becomes critical for workers aged 50 years and more. The musculoskeletal strength of the body starts to decline after the age of 30, and a 60 year old

has muscular strength which is approximately 70% of a 30 year old [7]. Balance disorders and risks of falls and injuries lead to a decline in work performance in sitting, standing, walking, leaning and stooping positions [8]. Joint mobility reduces considerably with age; however, its severity and level depends on the joint and type of motion [9]. Reaction time variability is higher in older people and directly affects work performance [10]. This decline in reaction time is more prominent in older women as compared to men [11]. Similarly there are relationships between functional capacity, vision and type of task performed by older workers [12]. There are a number of other performance factors including fatigue, memory deterioration and thermoregulation problems faced in extreme environmental conditions, which are influenced by age and affect work performance.

To conclude, in the light of above discussion, it is very important to understand all the physical, physiological, psychological and cognitive changes that result from ageing. On the other hand, there are a number of other factors like experience, decision-making, loyalty to the organization, sense of responsibility and critical thinking which make older people a real asset for organizations. The removal of an experienced and skillful older worker is not simply the loss of one person; it is also a drainage of skills, knowledge, experience and relationships and to regain these attributes, needs resources in the form of money and time [13].

3. Digital human modelling and workplace risk assessment

To accommodate older workers in workplaces, it is considered extremely important to investigate design solutions at an early design stage. Moreover, earlier product and process design evaluations are equally important in keeping design costs at reasonable levels, as redesign costs increase the final cost of the product. Computer-aided simulation tools, such as digital human modelling tools (DHMs) are effective in facilitating proactive ergonomic design investigations. However, it is very important to ensure that DHM simulation results are delivering valuable outcomes in terms of workplace improvements. Studies investigating the relationship between DHM simulation results and real life assessment reached the conclusion that the correlation is fairly high [14]. Furthermore, it was also found that certain workloads, such as static postures might be detected more reliably in DHM simulations as compared with real-life assessments. However, estimation of action forces is difficult to estimate through DHM simulations as their direct observation is rather difficult [14, 15]. In spite of the many limitations of DHM tools, it has been concluded that early design investigations based on digital human modelling can substantially reduce overall product development costs including design, engineering and ergonomics evaluation costs. In part this is because these tools enable the development and testing and assessment of a virtual product prototype without any real contact with users and operators. Similarly, designers can check different options before going for actual production and so expensive product design and development costs can be reduced significantly.

There are many digital human modelling systems commercially available such as SAMMIE, JACK, RAMSIS and their effective use in product, process and workplace design has been reported in many studies. A more recent digital human modelling based tool, HADRIAN, is explicitly aimed at an 'inclusive design' or 'design for all' philosophy based on SAMMIE. Data was collected for 100 individuals having a broad range of human capabilities with special attention to older people and people with disabilities. A database provides data about their age, capabilities like joint range of motion, body shape, anthropometry, experiences and preferences with a range of daily activities including domestic and transport related tasks. Data is held on individuals and is not used to form statistical representations of populations as is most common in DHM systems. HADRIAN is also equipped with a task analysis system where accessibility issues are reported at the level of individual subjects. Virtual individuals with their task performing capabilities are used to carry out any task analysis and results show why an individual is excluded and how these issues and problems can be eliminated. Previously, it has been successfully used for daily living activities like kitchen activities, use of ATMs by wheelchair users, and transport-related activities. However, this human modelling inclusive design strategy has not previously been used for industrial activities [16].

This paper focuses on the use of a DHM-based inclusive design strategy for industrial activities like manufacturing assembly activities where most of the work is done manually and ergonomics issues include demands for physical effort, repetitiveness, quick and fast movements with high level of productivity and quality. For the validation of this concept, older workers' capabilities (joint mobility) data are used to assess assembly related tasks.

4. Method

Digital human modelling was used for the concept validation of using a human modelling based inclusive design strategy in a manufacturing assembly environment. Data captured at a furniture manufacturing company was used for human modelling based risk assessment of the working strategies adopted. Assembly workers were recorded to capture a variety of working strategies, methods and procedures. Selected snap-shots of a variety of workers performing similar tasks were used for the purpose of analysis. The SAMMIE human modelling tool was used to generate a CAD model of the working environment that includes the sofas that are being assembled, tools used during the assembly operations and other relevant objects. Selected postures recorded in the factory were replicated by human models in SAMMIE. SAMMIE has the capability of developing a customized human by defining different anthropometric and capability data like joint mobility constraints. Actual joint mobility data of 31 workers who were older than 40 years has been used to assess suitability of working postures or strategies. Postures adopted in the real assembly working environment have been replicated virtually by these 31 older workers where their joint mobility constraints data has been used as a criterion for the acceptability of postures.

It provided the following upper extremity joint constraints: Arm flexion; Arm extension; Arm abduction; Arm adduction; Arm medial rotation; Arm lateral rotation; Shoulder flexion; Shoulder extension; Shoulder abduction; Shoulder adduction; Elbow flexion; Elbow extension; Elbow pronation; Elbow supination; Wrist flexion; Wrist extension; Wrist abduction; Wrist adduction.

5. Concept validation – A case study at a furniture manufacturing company

Figure 1 shows three workers carrying out the same assembly operation at a workstation. It is very clear that they are performing their task in entirely different ways. Differences in their working methods are significant in terms of tool handling, tool orientation, object or product orientation and body posture. It can be said that orientation of the object (sofa) and holding of a tool (drill) account for significant differences in adopted postures. The most difficult posture is adopted by worker 3 (method 3), where the position of the upper-arm, lower-arm, neck and orientation of the hand might be the assessment criteria for the acceptability of this method's inclusiveness. It is also clear that the positions of the upper-arm and lower-arm of worker 3 are the most awkward and differentiating features and have a direct relationship with joint mobility of the workers. It seems that a variation in joint constraints for the upper-arm and lower-arm for older people can make this method unsuitable for them.

Digital human modelling tools are capable of predicting risk involved during work, with an acceptable level of reliability. Use of the computer-based digital human modelling tool SAMMIE can provide information about the acceptability of these working strategies regarding their inclusiveness for older workers. For this purpose, computer-model of the workplace was created and virtual humans included to enable design assessments to be carried out. During this experimentation, all 31 workers (older) were evaluated performing each working method. In this way, 93 (31x3) scenarios were created and attempts were made to replicate actual working postures of older workers. The differences in joint mobility capabilities means it is unlikely that all older workers can adopt all these working postures. For the purpose of analysis, lower-arm and upper-arm positions of these actual working postures were replicated in SAMMIE. Assessment of a fully capable SAMMIE human model was first made to check whether or not a fully capable person can perform this particular activity in this way, and what level of joint mobility requirements are involved in any adopted posture. The joint constraints of a fully capable SAMMIE human model set the criteria for comparison of these (actual working postures with joint constraints of fully capable SAMMIE human model) and older workers (with limited and varying levels of joint mobility).

Complex body movements that contain both simultaneous bend and twist have a high level of risk at work and these must be avoided. Clearly, worker 3 (method 3) adopted a complex and relatively difficult trunk/back posture, where the main cause of this awkward posture was the orientation of the object (sofa). It can be seen that the orientation of the sofa for worker 1 and 2 was different, and this determined the view and height of the object (position of the working object with reference to face, shoulders etc.). Difficulty in viewing the working object and inappropriate height led worker 3 to adopt an unfriendly working posture where the neck is bent, the trunk/back is bent and twisted and one elbow is above shoulder level. In comparison with worker 3, worker 2 performed better in terms of level of risk, but worker 1 seemed very relaxed and comfortable during his work. Moreover, the working

strategies of worker 1 and 2 were different in tool holding and object holding, and positions of the shoulder were different. All these aspects can be seen in Figure 1.

The above discussion reveals that, differences in these work organization issues lead to entirely different working strategies where adopted postures demand different joint mobility capabilities. For example, the positions of the upper-arm and lower-arm are found to be different for these three working methods. For finding the exact joint mobility requirements necessary for a successful replication of these postures, the SAMMIE computer aided modelling system was used. The process started with capturing actual dimensions of the objects used during any working process. In this case, these objects were the sofa, work table and drill gun. After developing a computer-aided model of the work environment, a virtual human was placed appropriately and the actual posture replicated with a human model, to establish the joint mobility requirements. For this case study, the actual working postures of the assembly activity for three different methods have been replicated by a SAMMIE human model, and joint mobility requirements have been noted (figure 1). It is very clear from the snap shots that upper-arm and lower-arm movements are significantly different for these methods and are considered important for inclusiveness of these working strategies.

Figure 1 also illustrates that working method 3 imposes the highest level of joint mobility requirements, where the lower arm bend (R) demands a 141° extension which is high as compared with the other two methods, where it is 129° and 136° respectively. Similarly, right upper-arm swing value (113°) is also significantly higher than that of method 1 and 2 (47° and 92° respectively). So, these pre-defined joint mobility requirements can be used as criteria to investigate the acceptability of any method for a broad range of the population. The HADRIAN database consists of joint mobility data for about 100 people, of which 31 people are older than 40 years without any functional disability that can reduce joint mobility. The joint mobility data of these 31 older and fully capable people has been utilized to assess the acceptability of any working strategy for older workers at the individual level. As mentioned

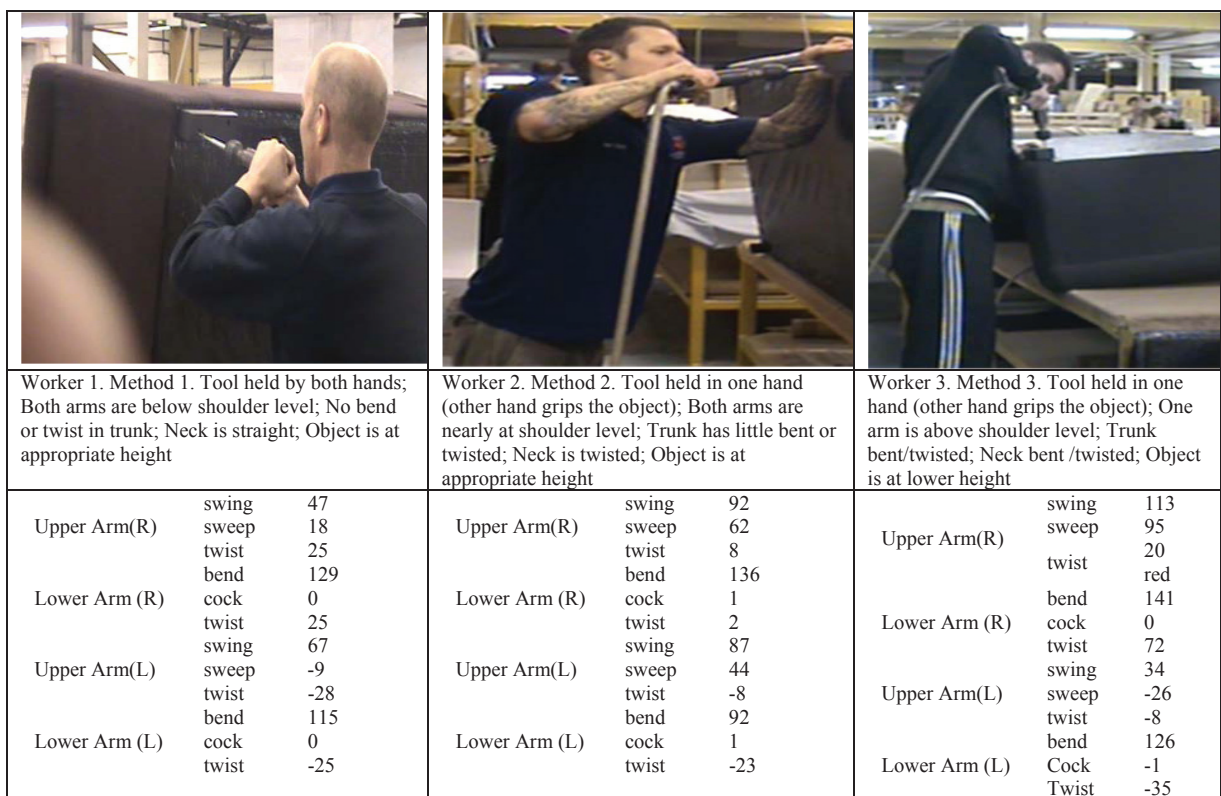


Fig. 1. Three workers performing same task with different methods.

earlier, SAMMIE has the capability of managing capability data for individuals, where a designer has to provide a manual input about all these parameters that defines any human's work performing capability.

During experimentation, 93 working postures were analysed where every older worker (virtual human with actual joint constraints of an older worker of HADRIAN database) was tested against the three different working methods shown in Figure 1. Figures 2, 3 and 4 show the examples of posture replication by SAMMIE (middle) and an older worker (right) against working methods 1, 2 and 3 respectively. Joint mobility requirements needed by a fully capable human (SAMMIE) for the approximate replication of an adopted posture, set a criterion for the acceptability of a method for any individual and older workers in general. The aim was to investigate whether or not the digital human modelling system SAMMIE can be used to investigate inclusiveness of any adopted working strategy.



Fig. 2. Using SAMMIE human modelling system to assess task inclusiveness for method 1.

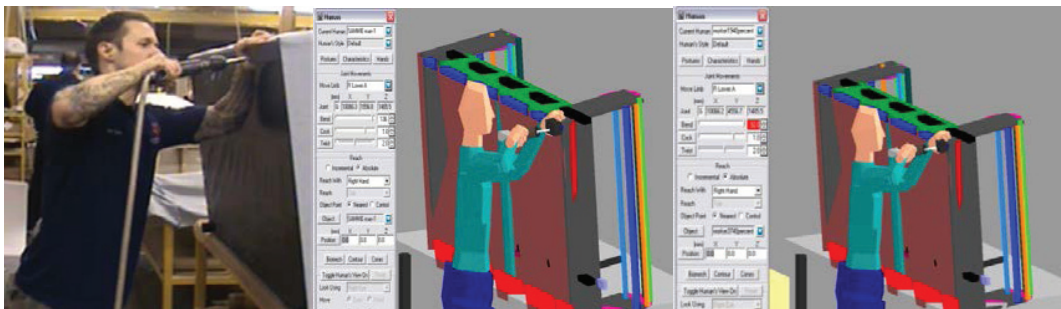


Fig. 3. Using SAMMIE human modelling system to assess task inclusiveness for method 2.

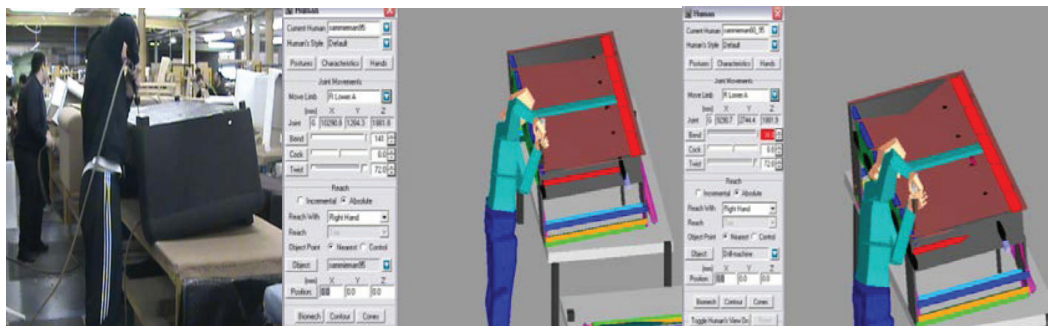


Fig. 4. Using SAMMIE human modelling system to assess task inclusiveness for method 3.

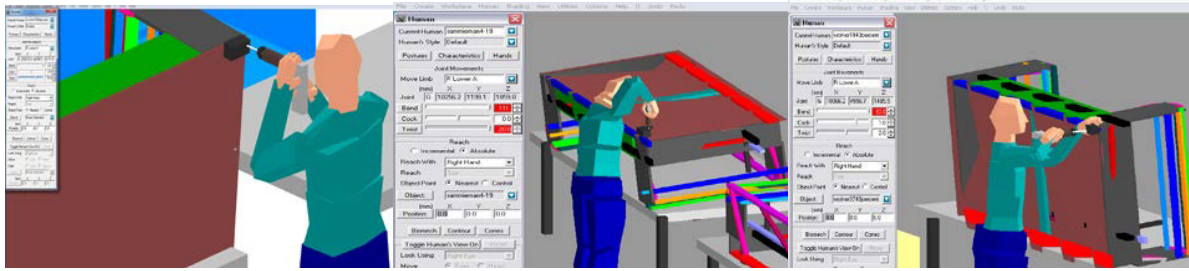


Fig. 5. HADRIAN database worker 19; design inclusion for work performing method 1, method 2 and method 3.

6. Results

This section is a detailed description of the design evaluation process through the SAMMIE human modelling system. Figure 5 shows the same worker (Number 19 in the HADRIAN database) with his own joint mobility constraints. For comparison purposes, he has been shown to perform the same activity in three different ways, shown previously. Here the aim is to assess whether or not he is capable of performing these activities based on his limited joint mobility as he is 73 years old. It has already been stated that methods 1 and 2 impose relatively less joint mobility requirements as compared with method 3. Here, figure 5 clearly indicates that worker 19 can easily accomplish this assembly task by adopting method 1. However, the same worker is unable to successfully complete the same assembly task element through methods 2 and 3. The red highlighting indicates violation of joint constraints and unacceptability of these two methods for this worker. It can be concluded that a person with limited joint mobility can easily perform this assembly task by adopting work method 1. Unlike method 1, the other two methods demand high joint mobility requirements and make them unacceptable for the same worker.

As described above, the database has been used to define 31 older workers (>40 years of age) with individual joint constraints and then tested against these three working methods for the same assembly activity. The results indicate that work method 1 is acceptable for 84% of the older workers, which is the highest proportion as compared with 48% and 19% for methods 2 and 3 respectively. Only 5 out of 31 older workers were found to be excluded for method 1, whereas 16 and 25 were excluded for methods 2 and 3 respectively.

The above results indicate the usefulness of the DHM-based inclusive design method where designers, ergonomists, engineers, managers and planners can promote such work practices that are equally acceptable for a broad range of the population, for example, older people in this example. The results clearly indicate that method 1 is the optimal solution in terms of its acceptability for older workers, based on joint mobility criteria. As all these assessments are based on the captured working strategies adopted by different workers, so the pool of available solutions can be increased by capturing more workers.

7. Strengths and limitations

This case study has shown a great potential for using the digital human modelling technique for the promotion of an inclusive design approach in industrial applications. In the future, workforce diversity will increase and people with different backgrounds, cultures, sizes, shapes, age and experiences will be sharing the same workplaces. The inclusive design method provides an opportunity to address all these issues proactively so that safe, healthy and productive workplaces might be assured. In future, organizations will have to think more seriously about these human variability issues, so that they can retain their skilled and experienced workforce, which will be a key driving force for achieving organizational sustainability. This study provides an idea about how the proposed inclusive design method can work for the benefit of individuals and organizations, in terms of workplace safety, productivity and human well-being. It also highlights the importance of the availability of more realistic human capabilities data (physical, physiological and cognitive) and use of that in an appropriate design tool.

On the other hand, validation of the proposed method has been carried out only for furniture manufacturing assembly activities. There is a need to validate the method against more industrial applications where its usefulness

can be assessed against a variety of applications. Moreover, this case study has only used the physical capabilities context of human working capabilities, but the concept should also be validated for some more complex dimensions of human capability such as physiological, psychological and cognitive abilities. Similarly, older workers' capability data is not limited to joint mobility; there are many other functional capabilities that decline with age, so other available data should also be used to promote healthy and safe working of the ageing workforce. Initially, the proposed method has been validated through SAMMIE, where older worker's joint mobility data has been used manually. Previously, the HADRIAN automated task evaluation method (based on SAMMIE human modelling) has been used for some simpler applications like kitchen based activities, use of ATM machines, and transport related activities. There is a need to enhance the automated task evaluation capability of HADRIAN from simple activities to more complex industrial activities like manual assembly operations.

8. Conclusion

A digital human modelling based inclusive design approach is considered useful for addressing work-related issues of a diverse workforce, especially older workers. Like joint mobility data, other functional capabilities data can be collected and used for assessing whether or not working conditions, environments and strategies are suitable for a broad range of the population. This proactive design approach benefits individuals and organizations by securing safe working conditions where people, with their existing differences, can perform at their best. In this way, global workforce challenges of diversity and ageing can be addressed by promoting such design practices. However, still there is a need to capture more data about the human differences and effectively utilize that in appropriate tools, so that more realistic work strategies can be implemented.

References

- [1] Williams, K.Y., O'Reilly, C.A., 1998. Demography and diversity in organizations: A review of 40 years of research. *Research in Organizational Behavior* 20, 77–140.
- [2] Shore, L.M., Chung-Herrera, B.G., Dean, M. A., Ehrhart, K.H., Jung, D.I., Randel, A.E., Singh, G., 2009. Diversity in organizations: Where are we now and where are we going? *Human Resource Management Review* 19, 117–133.
- [3] Richard, O.C., 2000. Racial diversity, business strategy and firm performance: A resource based view. *Academy of Management Journal* 43, 164–177.
- [4] Childs Jr., J.T., 2005. Managing workforce diversity at IBM: A global HR topic that has arrived. *Human Resource Management* 44, 73–77.
- [5] Bassett-Jones, N., 2005. The Paradox of Diversity Management, Creativity and Innovation. *Diversity Management, Creativity and Innovation* 14, 169–175.
- [6] O.N.S., 2009. Population trends 137 - Autumn 2009. Office of National Statistics.
- [7] Wanger, S.G., Pfeifer, A., Cranfield, T.L., Craik, R.L., 1994. The effects of ageing on muscle strength and function: A review of the literature. *Physiotherapy Theory and Practice* 10, 9–16.
- [8] Sturmiels, D.L., St George, R., Lord, S.R., 2008. Balance disorders in the elderly. *Neurophysiologie Clinique /Clinical Neurophysiology* 38, 467–78.
- [9] Chung, M.J., Wang, M.J., 2009. The effect of age and gender on joint range of motion of worker population in Taiwan. *International Journal of Industrial Ergonomics* 39, 596–600.
- [10] Hultsch, D.F., MacDonald, S.W.S., Dixon, R.A., 2002. Variability in reaction time performance of younger and older adults. *The journals of gerontology. Series B, Psychological sciences and social sciences* 57, 101–115.
- [11] Der, G., Deary, I.J., 2006. Age and sex differences in reaction time in adulthood: results from the United Kingdom Health and Lifestyle Survey. *Psychology and aging* 21, 62–73.
- [12] Sue, B., 2008. The association between low vision and function. *Journal of Aging and Health* 20, 504–525.
- [13] Dychtwald, K., Erickson, T., Morison, B., 2004. It's time to retire retirement. *Harvard Business Review* 82, 48–57.
- [14] Fritzsche, L., 2010. Ergonomics Risk Assessment with Digital Human Models in Car Assembly : Simulation versus Real Life. *Human Factors and Ergonomics in Manufacturing and Service Industries* 20, 287–299.
- [15] Demirel, H.O., Duffy, V.G., 2007. Application of digital human modeling in industry, in: Duffy, V.G. (Ed.), *Digital Human Modeling*. LCNS 4561 Springer, pp. 824–832.
- [16] Marshall, R., Case, K., Porter, M., Summerskill, S., Gyi, D., Davis, P., Sims, R., 2010. HADRIAN: a virtual approach to design for all. *Journal of Engineering Design* 21, 253–273.