2003-01-2195

Redesigning Workstations Utilizing Motion Modification Algorithm

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ABSTRACT

Workstation design is one of the most essential components of proactive ergonomics, and digital human models have gained increasing popularity in the analysis and design of current and future workstations (Chaffin 2001). Using digital human technology, it is possible to simulate interactions between humans and current or planned workstations, and conduct quantitative ergonomic analyses based on realistic human postures and motions.

Motion capture has served as the primary means by which to acquire and visualize human motions in a digital environment. However, motion capture only provides motions for a specific person performing specific tasks. Albeit useful, at best this allows for the analysis of current or mocked-up workstations only. The ability to subsequently modify these motions is required to efficiently evaluate alternative design possibilities and thus improve design layouts. Utilizing the Memory-Based Motion Simulation (MBMS) algorithm (Park et al. 2002), movements of a lifting task were recorded by motion capture and then modified to create realistic movements for different scenarios: different statures of the subject and alternative workstation geometries. Based on the motion simulations, the current study suggested a preferred height of the workstation, which was determined by the motion that minimized the calculated low back compression force and joint-strength requirements. Also, the effect of human stature on the biomechanical stresses was evaluated.

INTRODUCTION

With the increasing awareness of the need to ensure the safety of our workforce, jobs are continually being reevaluated and workstations improved to minimize the worker's job-related stress. Substantial amounts of time and money are spent researching and applying risk-reduction strategies. One of the more recent strategies in physical job/workplace evaluation is to utilize human motion capture to record the movements of workers performing their jobs, and then using a digital human to visualize the kinematics required by to perform those tasks. This provides a digital representation of the movements and allows the user to quantitatively analyze potential risk of injury, based on several posture-dependent analysis tools (Raschke et al. 1996, Raschke 1994, Chaffin et al. 2001).

Trained professionals have become very good at using motion capture and digital human modeling to identify potential stressors, to which workers may be subjected during their job. Despite the level of accuracy provided through motion capture, the ability to quantitatively determine the necessary improvement is significantly lacking. This is mainly because motion capture only provides a specific motion preformed by a specific person for a specific task, and evaluating alternative designs would require additional motion capture experiments. Therefore, without costly additional experiments, the ability to evaluate "what-if" scenarios is significantly limited and could be largely left to more subjective analysis methods such as checklists. Digital humans can, have been, and are currently being used to do this, however the postural inaccuracy introduced through "keyboard and mouse" manipulation can rapidly degrade the validity of the analysis.

In the current study, an additional strategy for utilizing motion capture data is presented. Instead of conducting additional motion capture experiments for new workstation geometries and accommodation of different segments of the population, existing motion data will be modified to predict motions for the new scenarios. The Memory-Based Motion Simulation (MBMS) algorithm (Park et al. 2002) was used to modify an original movement recorded through motion capture in order to analyze alternative scenarios: to modify the subjects anthropometry and modify the destination of the task.

Human lifting motions that occurred in USPS workplaces were captured from a motion capture experiment. The motions were modified to create realistic movements for different scenarios – different statures of the subject and alternative workstation geometries. Based on the motion simulations, the current study suggested a preferred height of the workstation, which was determined by the motion that minimized the calculated low back compression force and joint-strength requirements. Also, the effect of human stature on the biomechanical stresses was evaluated.

METHODS

Human motions from common United States Postal Service (USPS) manual handling tasks were previously recorded using Ascension Technologies' Wireless Motion Capture system. In the USPS' original experiment, a large man, approximately 95th percentile with respect to stature and weight, performed a manual handling task of removing mail trays from the top of a mail processing cart and placing them in the highest and lowest possible location on a General Purpose Mail Cart (GPMC), as shown in Figure 1.

Figure 1. Dimensions of extreme tray heights in the General Purpose Mail Cart (GPMC).

There are five (5) different origins and potentially thirty-two destinations where the trays can be placed in the GPMC (sixteen on each shelf). Thus a minimum of 160 individual motions would be required if motion capture were used to record all of these permutations. Additionally, multiple captures of each movement are often recorded in the case that a captured motion that is undesirable or corrupted. The associated money, time, and effort that are required just in preparation of a comprehensive analysis can be exorbitant. Even after this undertaking, only the motions that were recorded can be analyzed. Any analysis of future modifications to the workcell or task parameters would require an additional motion capture session.

It is understood that humans cannot exactly reproduce the same movement, thus some variation exists even between repeated actual movements. Consequently, some discrepancy must also exist between actual and simulated motions. The Memory-Based Motion Simulation (MBMS) algorithm retains the pattern of the original motion in its prediction of alternatives, so simulated motions may in fact be more similar to their original motions than what could be expected from a human. Several simulated motions are presented, including possible layout improvements that may not have feasible with motion capture alone.

Previous analyses (Rider et al. 2000) using digital human models have shown that the large man, approximately 95th percentile with respect to stature and weight, is at risk of a lower back injury when placing a 25-lb tray to the lowest position in the GPMC, as shown in Figure 2.

Figure 2. Large man removing tray from the 1226F push cart and placing on bottom shelf of GPMC.

The MBMS algorithm was used to modify the original captured motion:

1. To estimate the <u>lowest acceptable height</u> for a shelf that a man of 95th percentile stature can place a tub without *significant risk* of a low back injury.

2. To estimate the <u>tallest stature of a man</u> that can place a tub on the bottom shelf of the current GPMC without *significant risk* of a low back injury.

For this study, *"significant risk"* is deemed present when the lower back compression force exceeds the NIOSH Action Limit of 3,400 Newtons (N).

Following common ergonomic design practices, the subject of the original experiment was chosen to represent a 95th percentile man, with respect to stature and weight. Pertinent physical characteristics of the subject are provided in Table 1. The subject was experienced in performing mail-handling duties.

Table 1. Physical characteristics of subject

	Gender	Height	Weight	Age
S1	Male	6'1"	95.5 kg	50 yr

In this experiment, only one (of the 160 possible) movement that was recorded with motion capture served as the root motion for the MBMS. This root motion was then modified for the two separate analyses. EDS PLM Solutions' Jack was used for visualization and analysis purposes.

MODIFIED DESTINATIONS

To determine the lowest acceptable height for the tall man to place a tray, the MBMS was used to simulate the motions of a digital human to different end-point heights. The end-point height was adjusted vertically in 10 cm increments, from -30 to +30 cm of the original values, as shown in

Figure 3.

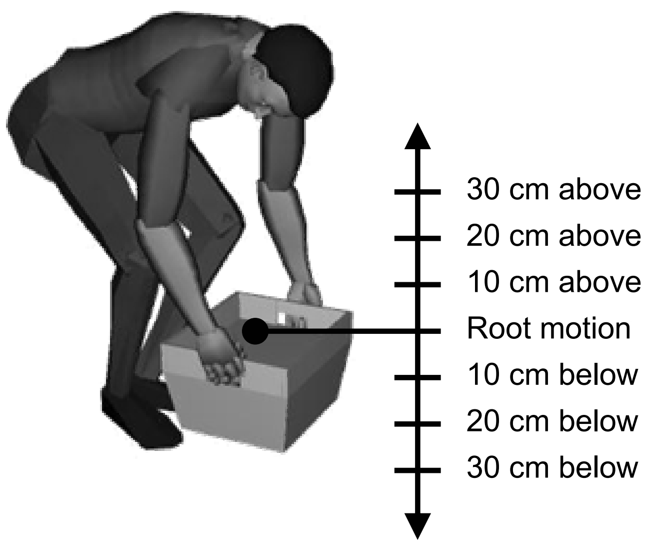

Figure 3. Depiction of vertical adjustments made to end-point destination of task.

The simulated motions from the MBMS were visualized and analyzed using a digital human, which represented the actual subject with respect to stature and weight. The motions to each destination were qualitatively compared with similar movements recorded through motion capture to illustrate the performance capability of the Algorithm. Further quantitative analysis was performed using *Jack*'s Lower Back Analysis tool.

By graphing the low back compression force over time for each motion, the maximum force on the back can be easily compared. Comparing these results to the NIOSH Action Limit, the results can be interpolated to determine the threshold height at which a worker would be subjected to an increased risk of a low back injury.

MODIFIED ANTHROPOMETRY

In order to determine the tallest stature for which this lowering task would be considered safe, the MBMS simulated the motions of digital humans of different statures. Seven digital humans were created for this analysis: one that represented the actual subject and six that ranged from 70% to 130% of the subject's stature and weight in 10% increments.

Similarly to the previous experiment, the low back compression force of the simulated motions is then plotted against time for comparison. Again, interpolation of the results yields the maximum stature of a worker that can safely place a tray on the bottom shelf of the GPMC.

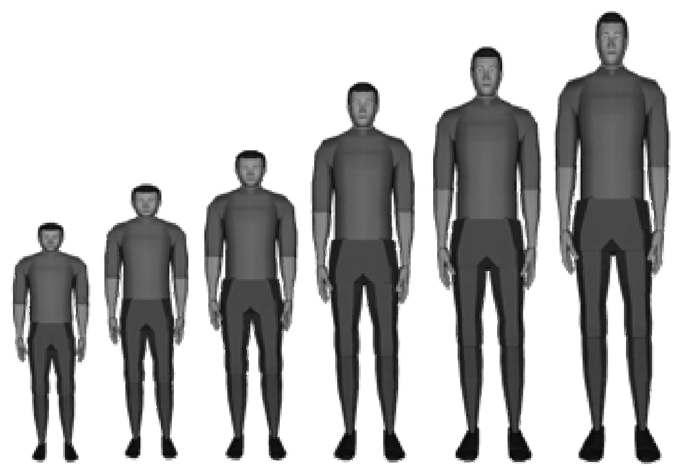

Figure 4. Stature comparison of the digital humans used in this study.

RESULTS

MODIFIED DESTINATIONS

Analysis of the original root motion revealed that the subject was subjected to approximately 3,800 N, which exceeds the Action Limit by 400 N. The other six motions were plotted on the same graph, and are shown in Figure 5. It can be seen from the graph that a 187-cm tall man can safely place a 25-lb tray on a shelf that is approximately 20 cm above the actual shelf.

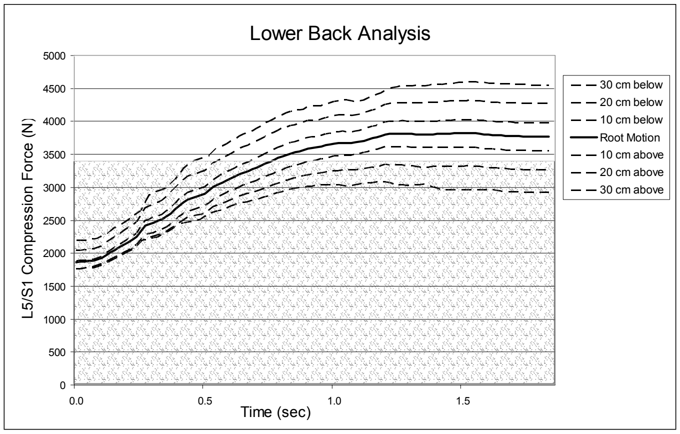

Figure 5. Graph showing the comparison of the low back compression forces that would be expected for a 187-cm tall man lowering a 25-lb tray to seven different heights.

Figure 6 further illustrates the vertical adjustments made to the destination of the task, while retaining the characteristics of the original root motion.

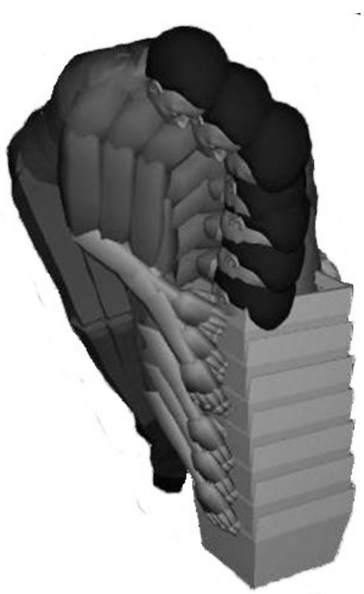

Figure 6. Example of digital humans of identical stature lowering a mail tub to vertically adjusted end-points.

MODIFIED ANTHROPOMETRY

Using the same methodological approach, interpolation of the low back compression force on the workers suggests that 177 cm is the tallest stature of a man that can safely place a 25-lb tray on the bottom shelf of the GPMC, as it is currently configured, as can be seen in Figure 7.

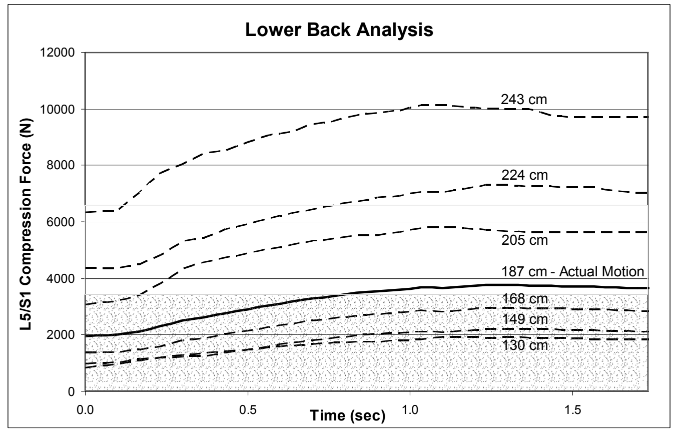

Figure 7. Graph showing the comparison of the low back compression forces that would be expected from workers of seven different statures.

Figure 8 further illustrates the vertical adjustments made to digital human's stature, while maintaining the end-point hand position.

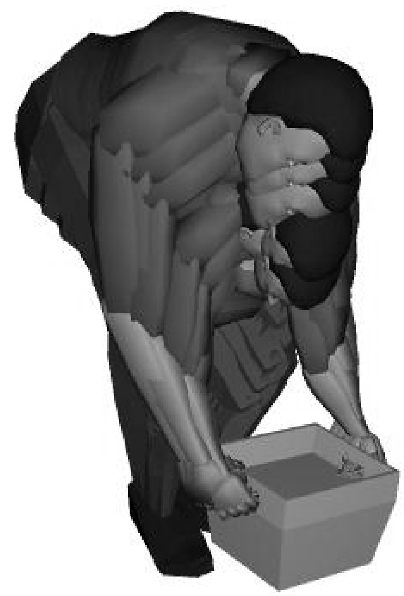

Figure 8. Example of digital humans with varying stature lowering a mail tub to the same destination.

DISCUSSION

A real human motion from a motion capture experiment was modified to create motions for alternative task scenarios – different workstation heights and statures for the subject. The motions generated by the motion modification algorithm exhibited smooth human motion patterns, as the modified motions preserve the naturalness of the existing motion data. This observation is consistent with previous studies that confirmed the prediction accuracy of the motion algorithm (Park et al. 2001a, 2001b).

The force-time curves shown in Figure 5 and 7, which correspond to motions generated for different scenarios, also display the similar shape of curves despite the difference in the absolute magnitude. This shows that MBMS indeed preserved the general movements of the original root motion, not only in the joint-angle-time domain but also kinetics domain.

The proposed approach of combining motion capture and MBMS was shown to answer important 'what-if' questions essential in ergonomic task evaluation and redesign (Figure 5 and 7): Figure 5 provides a range of destination heights that would not impose serious biomechanical stress on the worker's lower back. Figure 7 shows the effect of human height on the stress from the task. In fact, the result confirmed the initial report form the USPS that a tall-person might be subjected to low-back injury risk (Rider et al. 2000).

The combination of motion capture and MBMS has a significant advantage over the conventional motion capture experiment, as it saves the time and effort of conducting additional motion capture experiments. In addition, it may also complement existing human motion simulation models that predict typical, stereotyped motions such as reach and lifting (Chaffin 2002, Faraway 2002, Faraway and Hu 2001). When a task and its workplace are very unique and the motions occurring in the task are not 'stereotyped' motions, the existing motion simulation models may not be applicable. In such cases, a quick motion capture experiment and motion modification would enable designers to consider human motions in alternative designs with minimal effort and time requirements.

Limitations of the present study are acknowledged: The results of this evaluation are clearly subjective to the accuracy of the digital human modeling package as well as the experience of the experimenter. Regardless of the precision of evaluating the actual risk of injury for the workers, the relative risk increases and decreases in magnitude as would be expected which provides sufficient verification.

It must be noted that extreme caution should be used when performing an ergonomic evaluation with only one analysis tool. Rarely is the result of one analysis tool sufficient to justify significant changes to any job. Multiple sources should be compared and contrasted, as individual tools will provide insights to different aspects of the task.

There are numerous methods to qualitatively and quantitatively analyze a task. It was not the goal of the present study to determine an improved design for the GPMC, rather than to show how one could approach a redesign using the Memory-Based Motion Simulation or similar algorithm. The method utilized herein does not determine an optimum solution; however performing these and other steps programmatically could potentially produce such as tool.

ACKNOWLEDGEMENTS

The authors wish to thank the United States Postal Service for allowing us to use their data and simulate one component of their mail-handling processes. Please note that the original task parameters in this study were modified slightly to maintain confidentiality of the results from the USPS original experimentation.

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