

The Use of Physical Props in Motion Capture Studies

Monica L. H. Jones, Jim Chiang and Allison Stephens

Ford Motor Company

Jim R. Potvin

McMaster University, Canada

Copyright © 2008 SAE International

ABSTRACT

It is generally accepted that all postures obtained from motion capture technology are realistic and accurate. Physical props are used to enable a subject to interact more realistically within a given virtual environment, yet, there is little data or guidance in the literature characterizing the use of such physical props in motion capture studies and how these effect the accuracy of postures captured. This study was designed to evaluate the effects of various levels of physical prop complexity on the motion-capture of a wide variety of automotive assembly tasks. Twenty-three subjects participated in the study, completing twelve common assembly tasks which were mocked up in a lab environment. There were 3 separate conditions of physical props: Crude, Buck, and Real. The Crude condition provided very basic props, or no props at all, while the Buck condition was a more elaborate attempt to provide detailed props. Lastly, the Real condition included real vehicle sections and real parts. Plant operator subjects were also provided video feedback of themselves performing the task in the actual assembly plant, to ensure a similar method was used in the lab. Analyses of the postures adopted for each of prop levels indicate that there are differences associated with each. Relative to the motion capture using real automotive parts, there were marginal differences as the assessment progressed from crude to more complicated physical props.

INTRODUCTION

Virtual reality (VR) and motion capture (MOCAP) technology provide significant potential for obtaining accurate whole-body movements (Wilson, 1999). The postures captured in a MOCAP simulation are based upon the movements of real subjects. Specifically, this technology allows an operator to become immersed within a virtual environment. Body markers are used to track and transpose the human subject onto a digital human model (DHM) manikin. These movements can then be analyzed using a software package such as Jack (Siemens PLM Software Inc, Plano, TX) as the DHM manikin provides all the inputs necessary for a comprehensive ergonomic assessment. This approach

can improve the simulation time, provide more accurate posture predictions and capture the variability in movement represented on the assembly plant floor. It is generally accepted that all postures obtained from motion capture technology are realistic and "assembly representative". Yet, caution must be emphasized in that there is a broad need for direct comparisons of human behaviour in virtual and real environments (Stoffregen *et al.*, 2003).

To enhance the motion capture process, video of an assembly operation in question is often provided to parameterize the industrial workstation. Further, the virtual computer-aided (CAD) environment should be built to replicate the assembly facility. The overall objective is for the subject to interact with both the virtual and physical environment in a motion capture lab in order to identify critical movements of the assembly operation in question.

Physical props are also used to enable a subject to interact more realistically within a given virtual environment. While complete physical replication in the virtual environment would yield the most realistic results, this would be both time consuming and costly. It is proposed that the degree to which physical props are necessary is dependent upon how the subject will interact with the virtual environment. For example, if a simulated posture involves bracing or leaning relative to geometric CAD data, it is reasonable to assume that an appropriate physical hard contact point is required for the subject (Figure 1). The process of determining the type, complexity and number of physical props required for an "assembly representative" motion capture simulation is largely undefined. The objective of the current study is to evaluate the postural differences that result under different levels of physical props compared to Real operators performing the task with real parts and vehicle sections from the assembly facility using motion capture technology. The goal of this study to help define the degree of physical props complexity and detail that is required during a motion capture study for each of the assembly tasks studied.



Figure 1: The images above show the physical props (Crude or Buck Level) (top) used to replicate a virtual environment (bottom) while evaluating the installation of a foam piece at the centerline of the vehicle.

METHODS

This study focused on understanding the level of physical propping that is necessary to capture a posture and accurately reflect the operation in assembly production. To this end, virtual and physical environments were constructed for 12 assembly tasks at varying degrees of complexity (Figure 1). The tasks had varying levels of prop complexity and subjects would use the props to interact more realistically with the selected environment. Visual feedback, of the subject's interactions with the virtual CAD geometry and workstation environment, was provided in all trials. The purpose of this design was to progress upwards in physical prop complexity from Crude to Buck props so that the joint kinematic variables could be compared with that from the Real subjects. This will help determine how complex and precise physical prop levels need to be to achieve valid and reliable results that compare favourable with what would have been obtained from Real workers in the manufacturing environment.

Subjects

Seventeen male and six female subjects, ranging from 25-50 years of age, participated in this study. Experience level and training of the individual subjects also ranged from experienced assembly operators (n=12) to non-operators/engineers (n=11). Summary demographics are presented in Table 1. For each workstation, a total of 3 assembly operators had experience with the task and were defined as the "Real" subject. For example, for Task #3, subjects 7, 8 and 9 served as the Real subjects and they were subsequently tested under Crude and Buck conditions for the other 11 tasks (for which they had no previous work assembly experience).

Table 1: Mean summary of subject descriptors

Plant	Workstation	Subject	Sex	Ht (m)	Mass (kg)	
Car Plant	1	1	M	1.70	73.2	
		2	M	1.75	93.2	
		3	F	1.68	68.0	
	2	4	M	1.73	86.4	
		5	M	1.80	83.4	
		6	M	1.80	84.8	
Trunk Plant	3	7	M	1.65	74.3	
		8	M	1.75	78.2	
		9	M	1.68	70.5	
	4	10	M	1.70	0.0	
		11	M	1.85	87.0	
		12	M	1.78	75.0	
Pilot Plant		13	F	1.65	82.7	
Engineer			14	F	1.73	59.1
			15	M	1.85	109.1
			16	M	1.88	111.4
			17	F	1.73	54.5
			18	F	1.68	70.5
			19	M	1.83	80.7
			21	F	1.70	60.0
			22	M	1.91	139.5
			23	M	1.57	67.0
			25	M	1.70	68.2
Average				1.74	77.2	

DATA COLLECTED

The study was conducted in the Human Simulation Laboratory at Ford Motor Company. Data were collected using a laboratory set-up comprising of a motion capture system, visual display of the virtual workstation and physical props. A Motion Analysis Corporation (Santa Rose, CA) passive optical system was used with 18 Hawk cameras collecting at a rate of 60 fps. Fifty-two markers were placed on each subject. A Calcium Solver skeleton was subsequently fit to the marker locations in the Motion Analysis EvaRT software. A projector displayed a real time image of the subject performing the task in the virtual environment on one of three walls for visual feedback.

Tasks

There were 12 individual assembly tasks in this study, 6 from a car assembly plant and 6 from a truck assembly plant. Before collection in the virtual lab, two operations from each of the assembly plants were evaluated for two individual operators and each were video recorded for approximately 5 job cycles. The operations were further broken down into functional tasks. A functional task was defined by the manipulation of a specific part or the use of a tool. Each operation included approximately 3 subtasks ($n = 2 \times 3 = 12$). See the Appendix for a pictorial description of the 12 tasks. Apart from the workstations being selected based on vehicle type, they were also selected based on work zone (i.e. the horizontal and vertical reach that the operator would have to apply the force in order to complete the job). The installation efforts for each task were derived from existing surrogate data or handheld force gauge testing on a limited sample size.

Physical Prop Levels

There were three levels of physical props evaluated. The "Crude" level required subjects to perform the assembly task with minimal physical props. It provided very basic props or no props at all (i.e. only the virtual environment conveying the relationship of the subject with respect to the vehicle and hand load location). The "Buck" condition involved a more elaborate attempt to provide detailed physical materials, including a mix of basic props (such as a lift table, resizable door openings, etc). A fundamental characteristic of the "Buck" condition was to provide feedback of physical hard-points to the subjects. Figure 2 illustrates the difference between the Crude and Buck prop levels for task #10. The final method, entitled "Real", included real vehicle sections and real parts. Real subjects were also provided with video feedback of themselves or other Real subjects performing the task in the actual assembly plant, to ensure a similar method was used in the lab. This was the best lab representation of the exact task performance and was repeated and simulated in the motion capture lab so that the body postures could be recorded for analysis. However, in some cases there was little difference between conditions (e.g. for Tasks 10-12, both the Buck and Real conditions were based on the vehicle section.

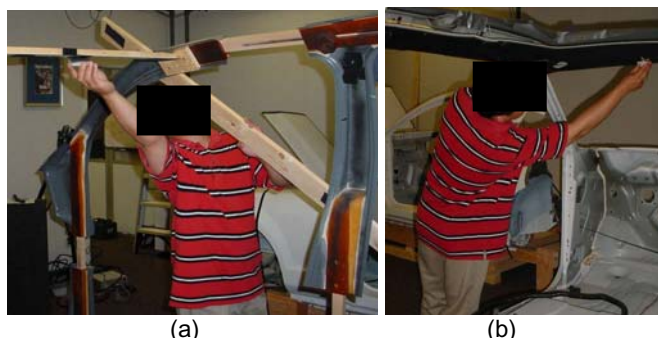


Figure 2: Physical Prop Conditions: a) CRUDE level – Task #10; b) BUCK level – Task #10

PROTOCOL

The three Prop Levels (Crude, Buck and Real) and 12 Tasks were presented in a randomized order within each of the four workstations. For tasks that subjects performed as Real, they were not tested with the Crude and Buck props. Each subject was given a set of instructions describing what they were required to do for each task. For each Task/Method combination, each subject would perform a practice session and then 5 trials were collected through motion capture. Each trial included: 1) the subject standing in a T-pose to ensure proper marker identification (arms abducted 90 deg to the side), 2) the subject performing the Task and holding the end position for 3 seconds, 3) a repeat of the T-pose.

DATA ANALYSIS

Three out of the five trials from each subject were processed for each Task/Method combination. Generally, the last 3 trials were used. However, if any of those trials had incomplete data, one of the first two trials was used as its replacement. The three-dimensional motion capture marker data was pre-processed in EvaRT software and a skeleton was derived. The skeleton was a linkage representation of the human body in the terminal posture which was mapped to a manikin in Jack software (Siemens PLM Software Inc, Plano, TX). The manikin used in Jack was based on the segment lengths from each individual subject and was the same sex as the subject.

Dependent Variables

Some key joint angle variables were recorded from the Jack outputs and these included all angles from the elbows, shoulder and trunk. Given that some tasks were performed with one hand, and this hand differed between subjects, weighted joint averages were also calculated. Weighted joint averages combined the right and left sides with values weighted by how much force was applied with that side. For example, when only the right hand was used, then the weighted elbow angle would be the same as the right elbow angle. When the right hand was used with 20 N and the left hand was used with 30 N, then the weighted elbow angle would be based on a 40% weighting of the right elbow angle and a 60% weighting of the left elbow angle. This calculation served to decrease the between-subject variability caused by the wide variety of postures observed for the unloaded arms, especially when subjects differed in which hand they used for one handed tasks. Various marker-to-marker distances were also calculated. For any loaded hand, the moment arm was estimated from the hand to both the shoulder and L5/S1. For anterior/posterior pushes and pulls (Tasks #5 & 8), this was calculated as the height difference between the hand and shoulder or L5/S1 (along the vertical Y axis). For vertical loads (Tasks #1, 3, 4, 6, 7, 10, 11, 12), this was calculated as the horizontal distance from the hand to