ADVANCED REVERSE ENGINEERING AND HUMAN MODELING

Robert C. Hale
Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201

Steven D. Harper
XonTech, Incorporated
2940 Presidential Drive
Fairborn, Ohio 45324

INTRODUCTION

Approximately 60 percent of life cycle costs of most new systems are related to human-in-the-loop design and maintenance costs. Because of this high cost, full-scale mock-ups and human subjects are being used to test systems for usability, maintainability and safety prior to final production. While good at finding human factors problems, test subject and mock-ups are expensive, time consuming, and sometimes dangerous. Access to high-speed computers have brought about sophisticated virtual human modeling and reverse engineering techniques that quickly replace much of the human testing during the early design stages.

The overall goal of this research is to apply reverse engineering and virtual human modeling techniques to measure reach in a virtual three-dimensional model of an F-16 cockpit. Our objectives are to (1) measure an F-16 cockpit using a coordinate measuring machine, (2) create a three-dimensional model of the F-16 cockpit, (3) use virtual humans to measure reach in the F-16 cockpit and (4) compare the results to real human data.

Virtual Human Modeling

The advent of virtual human modeling in computer-aided design (CAD) environments brings several advantages. First, virtual human figures with actual anthropometric dimensions can be shown interacting with CAD models of the system or machine. This creates a virtual prototyping capability to reduce the time required to evaluate physical prototypes for many types of human factors testing - usability, maintainability and safety. Second, three-dimensional simulations of human performance can quickly and inexpensively compare legacy systems with new or upgraded systems.

The virtual human modeling system - Design Evaluation for Personnel, Training and Human Factors (DEPTH) - is a design evaluation tool used for this study. The DEPTH modeling system, a product of the United State Air Force, integrates human test data from CREW CHIEF

Figure I. DEPTH human figure model

and the Jack human modeling systems. DEPTH has CAD import and export utilities, automatic human scaling features, anthropometric dimensions, solid modeling capabilities, human posture database, verifiable reach and access test capabilities and animation play-back features (see Figure 1).

As part of this study, we measured reach abilities of simulated F-16 pilots. Reach is affected by body size, posture, clothing, adjacent or interfering components, and the task performed.

The DEPTH model is a realistically detailed and biomechanically correct human figure that can be accurately scaled using anthropometric measurements from respected sources. The human figure has 74 segments, 73 joints, a realistic 22-segment spine, and 150 degrees of freedom. Also it is derived from anthropometric data validated by the ANSUR 88 survey.

Reverse Engineering

Reverse engineering is the process of developing CAD models from existing systems. The need for reverse engineering comes about for a variety of reasons (see Figure 2). Virtual human factors analysis often requires standard models for valid testing and comparison to legacy systems. When baseline CAD models exist, they are often two-dimensional, non-standard, incomplete, or expensive to obtain.

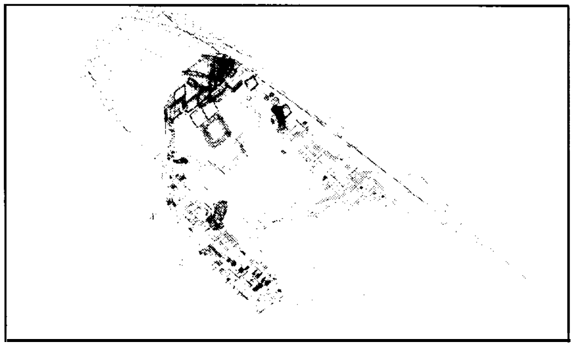

Figure 2. F-16 cockpit CAD model using reverse engineering techniques

Coordinate Measuring Machine

Coordinate measurement concerns the use of sample-point dimensional measurements. Dimensional measurement techniques are used to evaluate, verify, and validate products

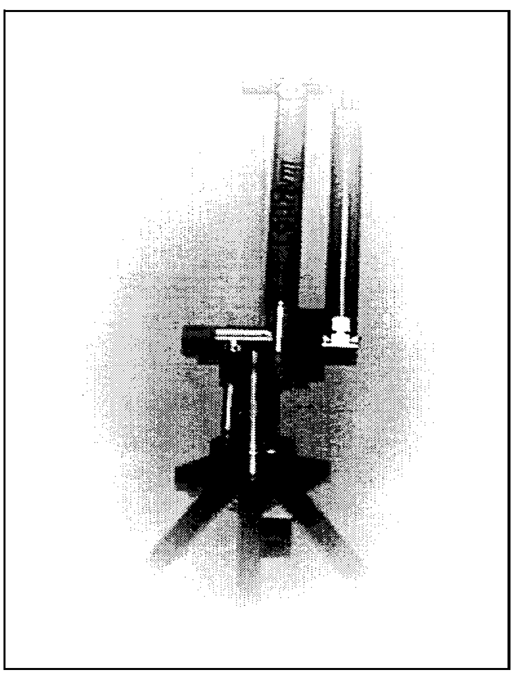

Figure 3. Coordinate measuring machine

according to their dimensional requirements. This technology involves the application of a measuring machine (see Figure 3) to digitize measurement points from the surfaces of products or work places. Measurement points are then applied to geometry algorithms. These algorithms generate the work surfaces and are used to determine the feature's conformance to tolerances.

METHOD

Measure F-16 Cockpit

A Faro Arm CMM was used to measure an F-16 cockpit. The Faro Arm is an instrumented, articulated measurement arm with 6 Degrees of

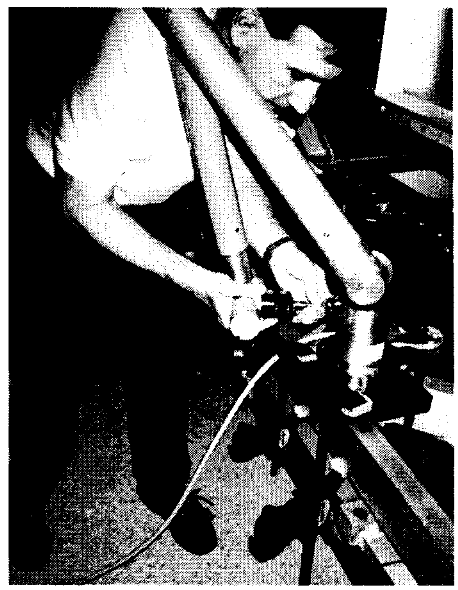

Figure 4. Measurement technique of faro arm

Freedom (see Figure 4). It is equipped with high-resolution optical encoders and captures data as individual points and streams of points providing an accuracy of 0.003 inches. A three-dimensional model was created and exported to the DEPTH human modeling software.

Human Data Collection

Six males and six females volunteered for this study. Nineteen anthropometric measures were taken for each subject as required by DEPTH to create a virtual human.

Plastic dowels, 1.0 inch diameter and 3.5 inches long, were suspended from posts on a pegboard representing the F-16 cockpit. Color markings were made around the center of the dowels to define the grasp site. The dowels were arranged so that they were located at sitting height, eye height (sitting), acromial height (sitting), elbow rest height and knee height (sitting) (Gordon, et al., 1989). The dowels were placed directly in front of the volunteer's right arm (0' offset), and the volunteers sat 30 and 60 cm from the rods (measured from back of chair to rods).

The subjects made contact with the dowels using a power grasp. The reach was considered successful when the markings were touched palm-first, and then the dowel was removed from the post. The subject was asked to reach for the rods by keeping his feet flat on the floor and knees straight. Hip rotation was allowed (Nemeth, 1998).

DEPTH Data Collection

Virtual human models were created in DEPTH by importing a database containing the subjects anthropometric data. The DEPTH interface was used to insert a human-figure. After insertion, a seated human model was moved to a location in the F-16 cockpit so that both feet were flat on the floor and knees straight. This procedure is similar to how the humans sat in front of the pegboard.

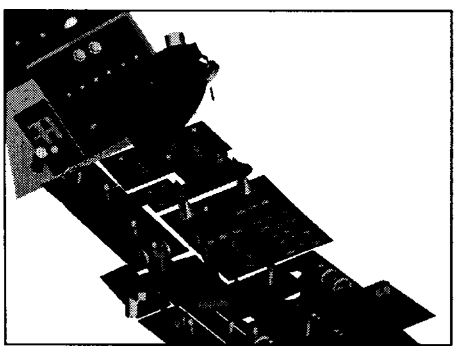

Figure 5. 3-dimensional rendered model of F-16 cockpit

DEPTH's human motion models were used to manipulate the virtual human. The grasp motion model was initiated, which directed the virtual human to attempt a grasp (see Figure 6). A grasp was successful when the model's palm was able to make contact with the virtual dowel site.

RESULTS

The distance for a completed grasp was identified for both the live and virtual humans, When the distances matched, the outcome was considered "accurate." The alternative outcomes accounted for under- or over-estimating the humans' reach abilities. As shown in Table 1, the maximum grasp-distance measured by the virtual human in DEPTH was an accurate simulation of their reach abilities for a majority of subjects.

Table 1. Comparison of DEPTH reach judgment with Human ability.

Height	Accurate Outcome of reach and grasp task	Under-estimation of human reach and grasp abilities	Over-estimation of human reach and grasp abilities
Sitting height	75%	25%	0%
Eye height	91.7%	8.3%	0%
Elbow rest height	75%	16.7%	8.3%
Knee height	91.7%	0%	8.3%

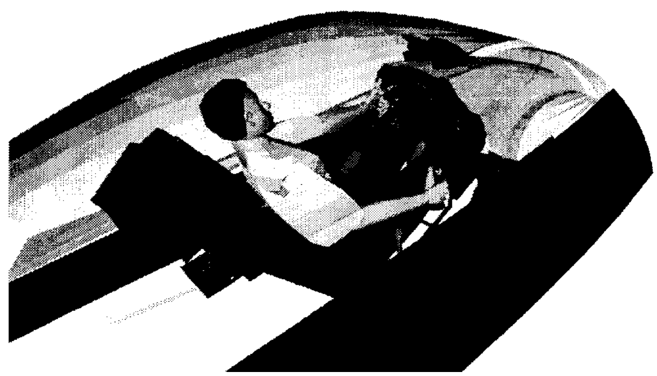

Figure 6. Virtual human figure in F-16 cockpit

DISCUSSION

The DEPTH human model was able to accurately simulate grasping behaviors in 83.3% of the trials. The most accurate levels were found at eye height and knee height. Overall, the

DEPTH human model is very accurate for reach and grasp tasks.

Underestimation occurred at sitting height, eye height and elbow rest height. Overestimation occurred at elbow rest height and knee height. While an underestimation represents a conservative simulation of reaching behavior, it can mean that usable space may be wasted. On the other hand, overestimation of reach can be dangerous (Nemeth, 1998). In a few cases, the DEPTH human model outperformed the corresponding human subject. This could lead a designer to locate important controls beyond the reach of an operator.

Although there are many individual differences between users when performing a grasping and reaching tasks, the DEPTH human model should be sufficient for a preliminary evaluation of cockpits.

Benefits of Reverse Engineering and Human Modeling

Reverse engineering is a low cost, high fidelity, and achievable method for solving the CAD dilemma for many organizations. In Figure 7, we compare the cost in labor hours of manual data collection versus the CMM method.

Also, it provides detailed, accurate CAD models required for virtual human modeling analysis. When used together, reverse engineering and virtual human modeling can quantify answers to engineering problems and provide cost effective support of design trade studies early in system development.

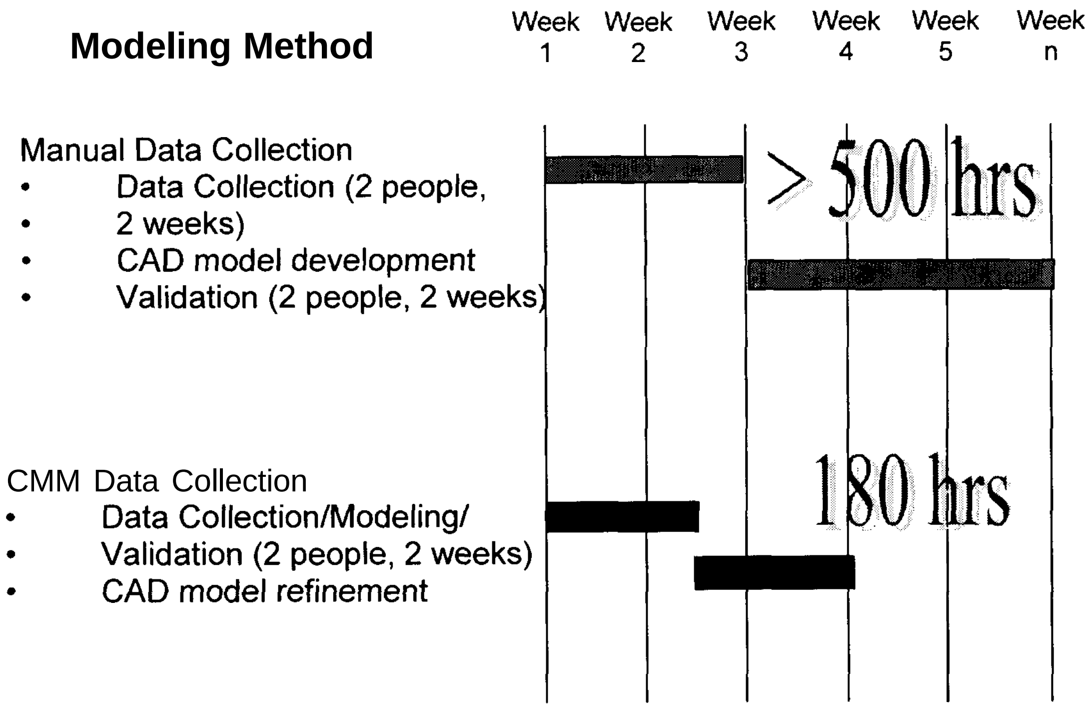

Figure 7. Manual data collection versus CMM technique

REFERENCE

Gordon, C.C., Bradtmiller, B., Clauser, C.E., Churchill, T., McConville, J.T., Tebbetts, I., and Walker, R.A. (1989). 1987-1989 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics. Technical Report NATICK /TR-89-044, U.S. Army Natick Research, Development and Engineering Center, Natick, Massachusetts.

Nemeth, K. (1998). Motion Analysis of a Virtual Human Technology. Air Force Research Laboratory. Wright-Patterson Air Force Base, Ohio.

University of Pennsylvania. 1994. Jack@ User’s Guide. Philadelphia, Pennsylvania.