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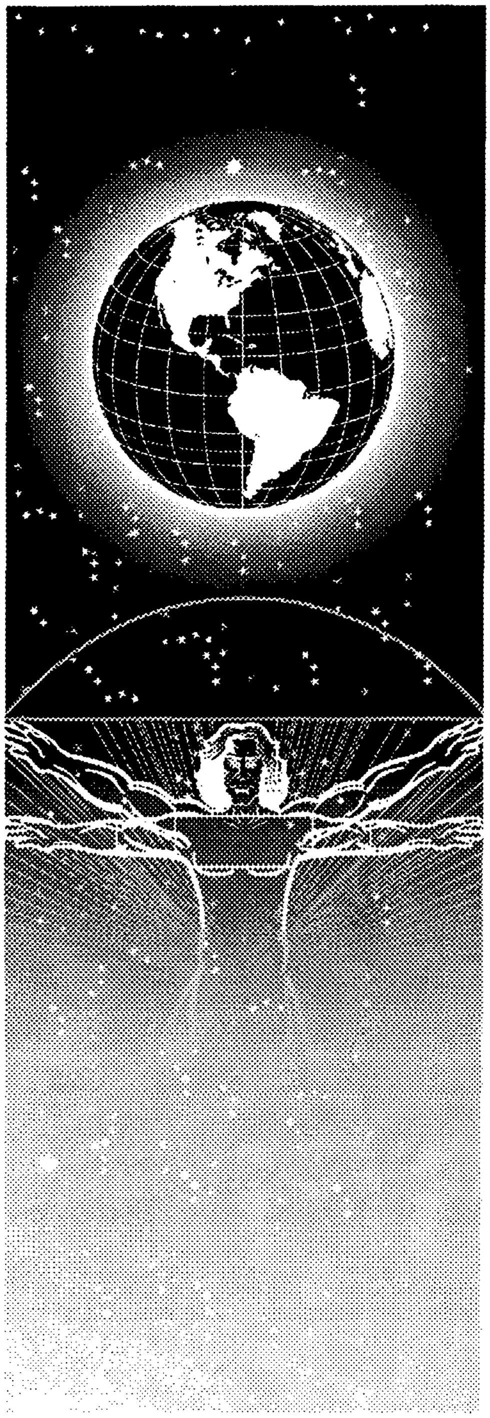

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Absolute Accuracy of the Cyberware WB4 Whole Body Scanner

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

KENNETH R. BOFF, Chief
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13. ABSTRACT *(Maximum 200 words)*
This report describes a study of the accuracy of the Cyberware WB4 whole-body scanner. CARD Lab researchers made multiple scans of a calibration object designed to simulate human body size and shape. Researchers then pinpointed landmarks on the scans using Integrate, a software package developed at the CARD Lab to manage and manipulate scan data. Dimensions in the scans were then compared to the actual size of the calibration object. Researchers concluded that the scans and the actual object were very comparable, that no systematic distortion occurred, and that errors caused by the scan landmarking process could be solved with enhancements to Integrate.

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PREFACE

This research was conducted by the Computerized Anthropometric Research and Design (CARD) Laboratory of the Human Engineering Division, Crew Systems Directorate, Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed under the Scientific Visualization of Anthropometry for Research and Design (SVARD) Contract Number F41624-93-C-6001.

CONTENTS

SUMMARY

This study, conducted at the Computerized Anthropometric Reseach and Design (CARD) Laboratory, investigated the accuracy of the Cyberware WB4 whole body scanner. Several CARD Lab research projects which rely on data collected by the WB4 scanner are either planned or underway. The integrity of the data collected with the WB4 depends entirely on the accuracy of the scanner.

In the study, we scanned a calibration object, designed to simulate human body size and shape, in various positions in the scanning space. After scanning, Matt Brunsman and Hein Daanen pinpointed landmarks on the scans using Integrate, a CARD Lab-developed scan data management software tool. The dimensions in the resulting scans were compared to the actual dimensions of the calibration object. Because the accuracy of the scan dimensions depended largely on the researchers who picked the landmark points on the scans, we examined the point-picking process as a possible source of error.

We made the following conclusions based on the study's results:

• The size of the calibration object (500 x 200 x 100 mm) was very well reproduced in scans made by the Cyberware WB4 scanner (501.3 x 199.8 x 102.1 mm). We determined that no systematic distortion occurred. This conclusion is supported by the finding that the absolute mean error in point picking did not exceed 2 mm.

• When landmarks have to be determined on a scan, the detected point may be 2.06 mm from the desired point due to the resolution of the scan. In determining linear distances, the possible error doubles to 4.12 mm. Approximately 90 percent of the study's point picking error was within the range of -4.12 to 4.12 mm. The larger errors may have been caused by human error during point picking or by missing points in the scan.

• Over 50 percent of the points picked were identical between the point-picking researchers.

• Point-picking error was independent of the vertical and horizontal location of the calibration object in the scanning space.

• Point-picking error was less in the vertical direction than in the horizontal direction, probably because the scanner's vertical resolution (2 mm) is better than its horizontal resolution (5 mm).

• We estimate that accuracy can be improved by 90% (to ± 0.5 mm) by using software that estimates a surface point between scanned points.

• The merging procedure (CyPie) calculates a good optimum out of the scans for each scanner head.

• Landmarking can be done accurately even when the scanned object sits at a sharp angle to the scanner head.

• The alignment file (best.align) should be checked regularly to prevent scanning distortion.

1.0 INTRODUCTION

The Cyberware WB4 whole body scanner is one of the first scanning systems in the world that generates a high resolution data set of the outer surface of the human body. The Computerized Anthropometric Research and Design (CARD) Laboratory at Wright-Patterson Air Force Base is using the scanner to gather anthropometric data quickly and reliably. We initiated a validation study to quantify the accuracy, reliability and errors of the system. This report describes the procedure and results in determining the absolute accuracy of the scanner.

The study consisted of three test conditions:
In the **first condition**, we scanned a calibration object with each side rotated toward a scanning head. Two researchers used Integrate, a scan data management software tool developed at the CARD Lab, to mark the three-dimensional (3-D) locations of 10 washers glued to the calibration object. This process was repeated as the object was moved to several different locations in the scanning space. This set-up enabled researchers to determine the accuracy for each scanning head as well as its dependency upon location in the scanning space. Moreover, the distance between the sides of the calibration object was determined, which indicates alignment errors between opposite scanning heads.
In the **second condition**, we scanned the calibration object with each side rotated toward the middle of two neighbouring scanning heads. The views from each separate scanning head were compared to the merged view to investigate alignment errors between scanning heads and the accuracy of the merging procedure.
In the **third condition**, we varied the angle of the scanning head to the sides of the calibration object from 0 to 90 degrees in 15-degree steps. This process allowed us to determine if the error increased when the calibration object was less perpendicular to a scanning head.
A schematic overview of the test conditions appears in Figure 1.

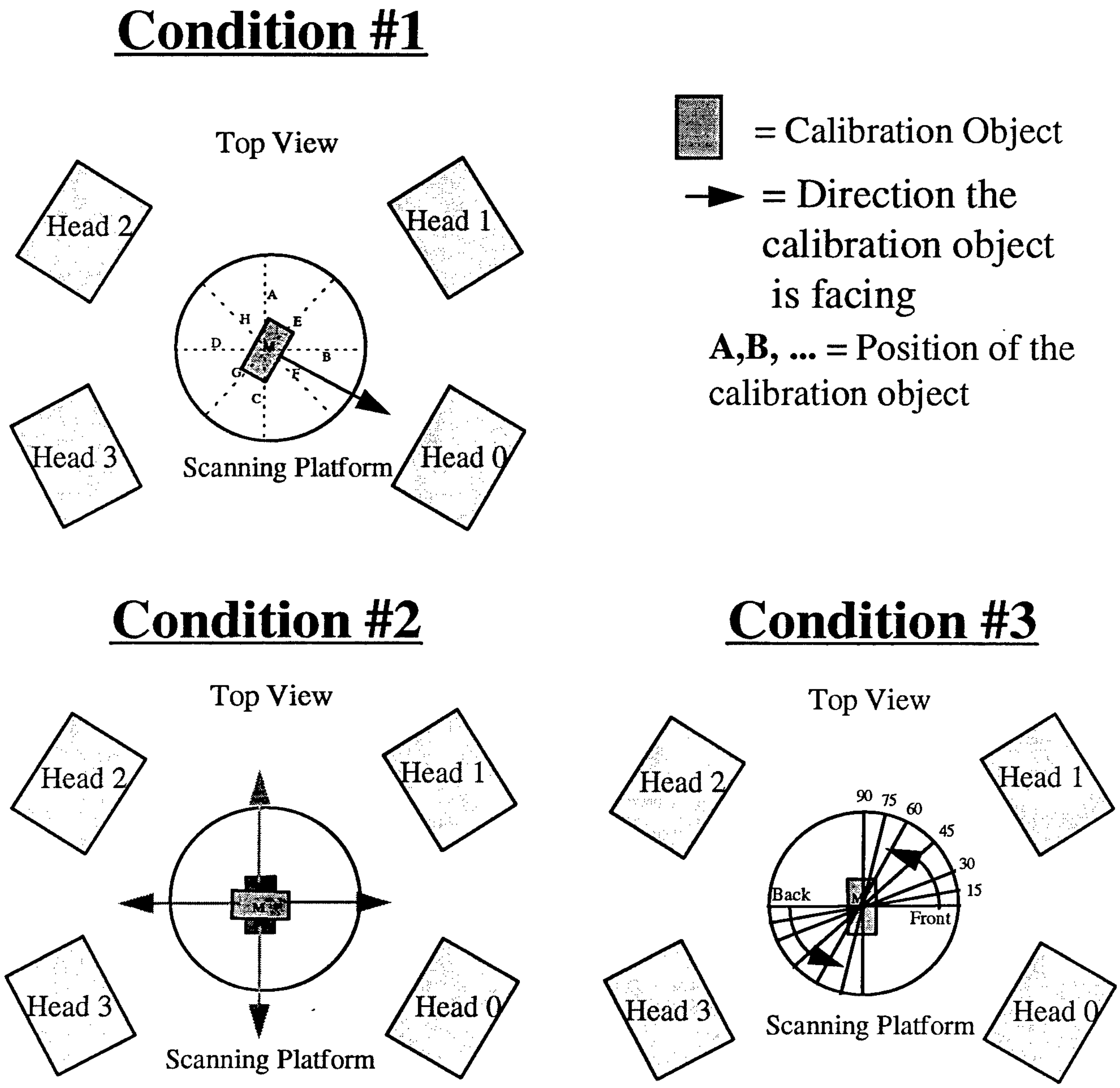

Figure 1: Schematic overview of the three test conditions with a top view of the Cyberware whole body scanner. C = calibration object, H = scanning head, x = measurement location.

2.0 MATERIAL AND METHODS

2.1 The WB4 Scanner

The Cyberware WB4 whole body scanner consists of four vertical moving scanning heads attached to a rigid metal frame (Figure 2).

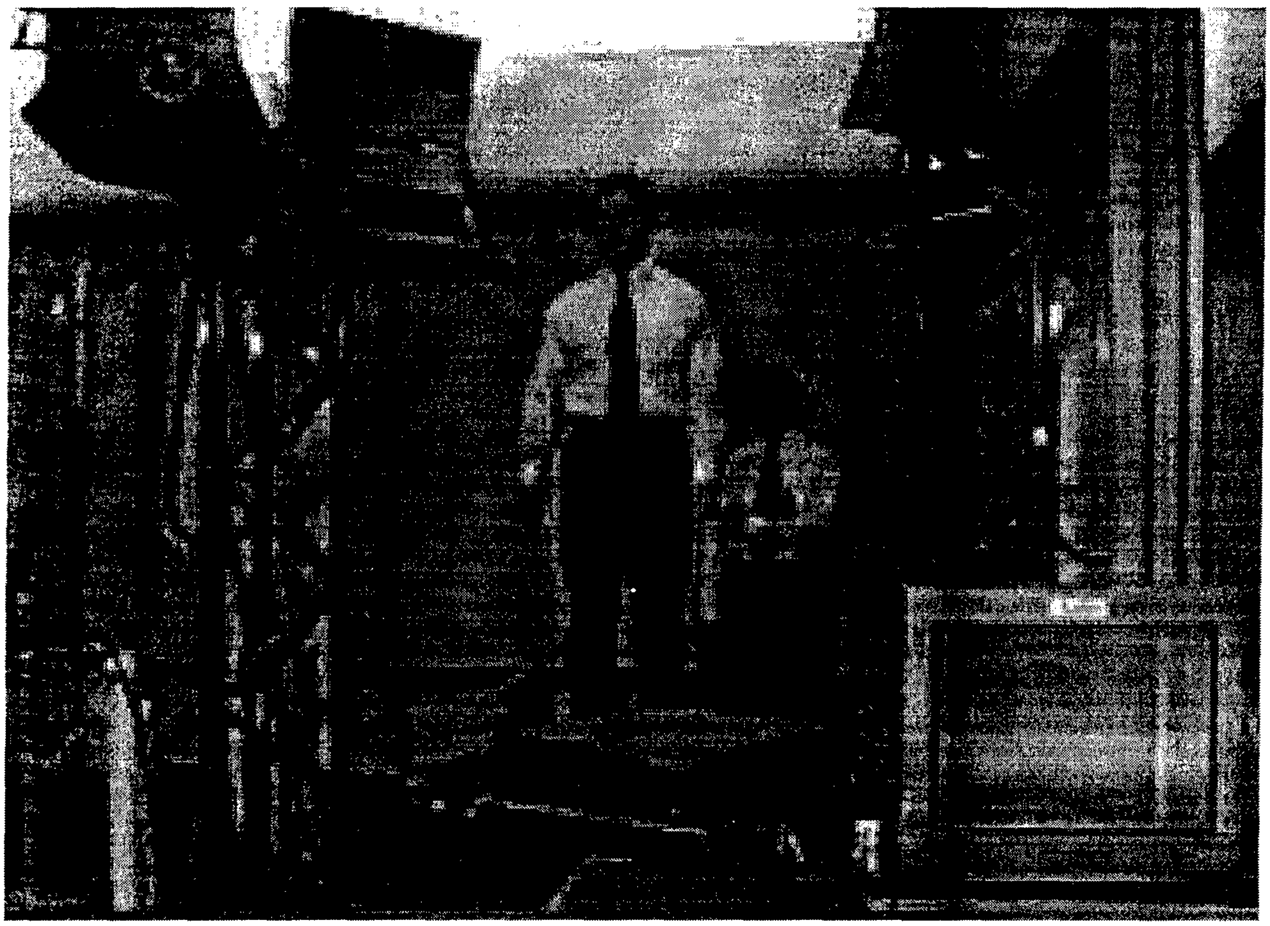

Figure 2: The Cyberware whole body scanner.

The scanning heads project a horizontal laser line on the scanned subject. The subject sits or stands on a round platform mounted to the scanner frame. The subject's entire body is scanned in about 17 seconds. The maximum scan volume is two meters high and 1.2 meters in diameter. The results of the scan are sent to a Silicon Graphics Indigo 2 Extreme work station by four SCSI ports. During this study, the upper surface of the platform was 458 millimeters (mm) high during scanning. The scanning height was set in the software at 450 mm to 2,450 mm. Thus, the underside of the scanned volume started 8 mm above the platform.

2.2 The Calibration Object

The calibration object (Figure 3) used in the study consists of three connected boxes which rotate around a pipe on a stand. The pipe is two meters long and 45 mm in diameter. The three boxes are:

- a top box 100 mm high, 200 mm wide, and 200 mm deep,
- a cylinder 100 mm high and 150 mm in diameter,
- a bottom box 100 mm high, 500 mm wide, and 200 mm deep.

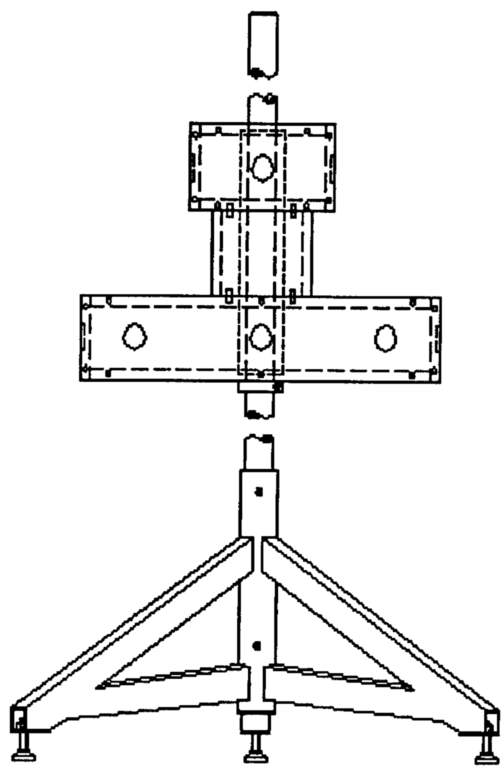

Figure 3: The calibration object.

The boxes are painted gray with holes (five mm deep and 30 mm in diameter) drilled in the center of each side. The sides of each box are also marked with several washers and colored dots. The white or red washers have an inside diameter of 10 mm and an outside diameter of 21 mm. Washers were glued on top of each other to achieve varying thicknesses. The washers are 1 to 1.5 mm thick. The washers used for the calibration in this study were on the bottom box, three washers high, and located on the edges. The colored dots were not used in this study, since at the time of this investigation errors in the Cyberware software made it difficult to locate the colors in space. A screw was connected to the bottom of the stand by small wires, so that it hung close to the scanning platform. This enabled us to place the object accurately above the markers on the platform.

2.3 Reference Axis

The reference axis for the study matched the axis system in Integrate, the scan data management software tool developed by the CARD Lab (Burnsides et al., 1996). The cross-section point (0, 0, 0) of all axes was located 1,010 mm above the middle point (M) of the platform. The positive y-axis pointed up. The positive z-axis pointed toward head 0, and the positive x-axis pointed to the right as seen from head 0 (see Figure 4 below).

2.4 Position of the Calibration Object in the Scanning Space

To investigate the dependency of the absolute error on the scanned object's location in the scanning space, we placed the calibration object at five different heights and nine different horizontal positions in the scanning space. The calibration object was fixed to the pole by a collar which could be attached and detached by an allen wrench. The vertical positions used are shown in Table I.

Table 1: Vertical positions of the calibration object.

position	vertical location (Y)
A	Lowest position: underside of box 245 mm from the floor
B	Underside of the collar 609 mm from the floor
C	Underside of the collar 1,010 mm from the floor
D	Underside of the collar 1,411 mm from the floor
E	underside of the collar 1,685 mm from the floor

The nine horizontal locations are shown in Figure 4 and listed in Table 2. The angle from the center of the platform (M) to head 0 was defined as 0 degrees.

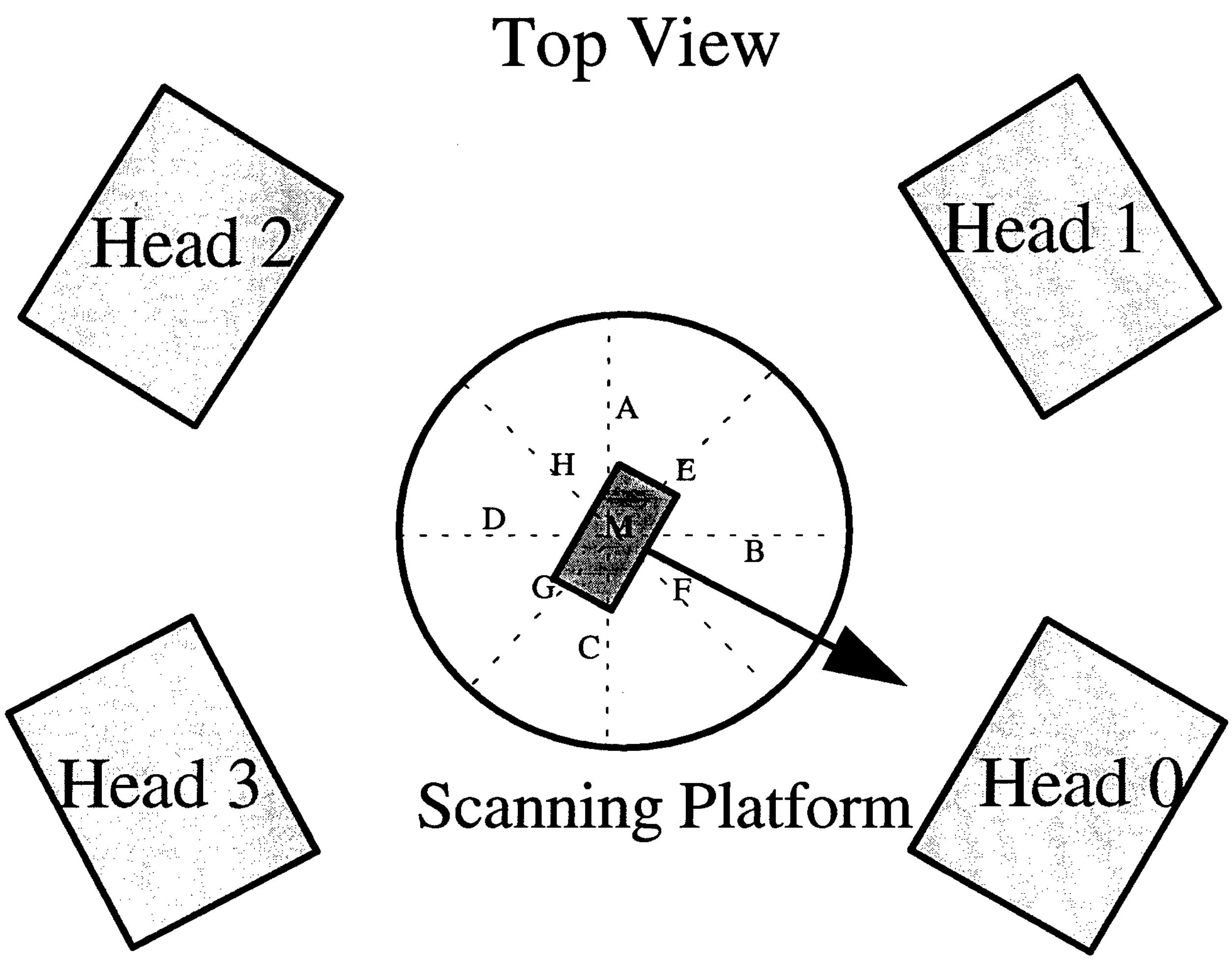

Figure 4: The scanning platform with the measurement locations in the horizontal plane.

Table 2: Horizontal measurement locations of the calibration object.

position	distance from M (mm)	angle (degrees)	coordinates (x,z)
M	0	-	(0,0)
A	293	180	(0,-293)
B	294	90	(294,0)
C	296	0	(0,296)
D	295	270	(-295,0)
E	175	135	(124,-124)
F	176	45	(124,124)
G	176	315	(-124,124)
H	175	225	(-124,-124)

All horizontal positions were marked with 6-mm green dots on the scanning platform and labelled with the corresponding character.

2.5 Scanning of the Calibration Object

First, we carefully positioned the calibration object at the correct height on the pole (A-E) and placed the calibration object on the scanning platform with the screw under the calibration stand located exactly above the markers on the floor (M, A-H). Next, we rotated the calibration object so that the front of the calibration object (the long side of the lower box with the most washers) was located exactly parallel to head 0 (for the accuracy study and the alignment of opposite heads), or exactly parallel to two neighbouring heads (for the alignment study of neighbouring heads). The correct angle to the head was controlled by means of two wires with small markers hanging down from the lower box to the floor. We positioned the two markers parallel to straight lines marked on the platform.

The lights on the scanner's light towers were off during scanning, and the scanning room was illuminated by indirect overhead light sources. All scans were done in March and April, 1996. The data acquisition was done by CyScan, Cyberware's data acquisition package.

The alignment of the scanning heads is determined by the Cyberware alignment file (best.align). The alignment values used during the scans were:

	global	head 0	head 1	head 2	head 3
angle	0	0	0	0	0
position	0	0	50	800	-150
radial	0	0	50	-20	700
scale	-	1	1	1	1

The separate scans were merged by Cyberware's CyPie program. We used the resulting merged files with .ply extensions for landmarking.

2.6 Landmarking

We loaded the scan files into Integrate, and followed these steps when landmarking the scans:

1) The default set-up (@vssetup or @assetup) was loaded. In this set-up the walls were set at 10; 7,000. The eye distance was set at 500 (Integrate adds 700 to make it 1200). The view started in the front mode. The wireframe was off, Points on, Surface off, RGB off, and Gouraud on.
2) The matrix and polygon mesh files were loaded. The transformation matrix file consisted only of a change of the orientation of the x-, y- and z-axis. The transformation matrix was:

$$P(x',y',z') = \begin{vmatrix} 0.00 & 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 1.00 \end{vmatrix} * P(x,y,z)$$

3) The object was oriented on the integrate axis (move, rotate).
4) The object was segmented (movie_seg ly0 uy200) to remove the pole and tripod and the full object was hidden (hide 1).
5) The surface was turned on (F2), as well as the transparency (shift F2). The points were turned off (F3).
6) The pickmode was turned on (F9) and landmarks were specified (pickmode auxland).
7) The template landmark file was loaded.
8) In the top view, the deepest point of surface of interest was aligned with the parallel corresponding axis (e.g. move 0 0 -94). In this way, irrelevant data points were absent in pickmode.

9) The surface was displayed on the correct side of the object.
10) The points were landmarked with a mouse. The cursor was located in the center of the washer.
11) Steps 8, 9 and 10 were repeated for the rest of the surfaces.
12) The landmark files were saved.

2.7 Statistical Processing

The results were analyzed with three statistical packages:
SYSTAT, version 4, modules DATA, STATS, and MGLH; STAT-EASE®, version 4.0.8CL; and SAS.

3.0 CONDITION 1: ACCURACY DETERMINATION OF EACH HEAD AND ALIGNMENT OF OPPOSITE HEADS

3.1 Methods

3.1.1 Statistical design

Instead of using a full factorial design (5 vertical x 9 horizontal = 45 observations) to measure the error, we used a reduced design called Central Composite Design (CCD). In CCD, observations (scans) are taken at center points and star or axial points. The center points estimate pure error and tie blocks together. The star points estimate pure quadratic effects (i.e. the x_1^2 and x_2^2 terms). The factorial portion of the design looks at the interaction between the independent variables.

Since the design space we wished to predict was unknown at the outset, it was important for the second-order design to possess a reasonably stable distribution of prediction variance ($N \, Var\hat{y}\,(x)/\sigma^2$) throughout the experimental design region. A rotatable design is one in which the prediction variance is constant on spheres. Center runs provide reasonable stability of prediction variance in the design region. For a rotatable design, α=1.682 units is the maximum radius of positioning. We measured the maximum useful diameter of the scanning platform and found it to be 59 cm, or a radius of 29.5 cm. Thus, the unit was 13.5 cm and α=17.54 cm.

We used DesignEase by STAT-EASE®, Inc., version 4.0.8CL, to input the requirements for a rotatable CCD. The test was conducted in two blocks. The first block consisted of 12 runs of eight factorial points and four center points. The second block had eight runs of six star points and two center points. These twenty measurements were performed consecutively as listed in Table 3. When the design called for duplicate scans, we repositioned the calibration object on the platform. The vertical position, however, was not changed.

We used a statistical technique called Response Surface Methodology (RSM) (Myers and Montgomery, 1995) to analyze the results. RSM is applicable where several input variables potentially influence some performance measure of a product or process. The intent was to determine the effect of location within the scan volume on the measured error. Location was varied both vertically and within a horizontal plane. Since the true response function was unknown, RSM was the experimental strategy: for exploring the space of the independent variables (vertical position and horizontal position); for empirical statistical modelling to develop an appropriate approximating relationship between the response and independent variables; and for optimization methods for finding the position which minimized the error.

Table 3: Consecutive measurements of the scanning object.

number	height position	horizontal position
1	C	A
2	C	M
3	D	G
4	C	B
5	D	E
6	D	F
7	C	M
8	C	M
9	E	M
10	B	F
11	B	H
12	C	M
13	C	M
14	C	M
15	B	E
16	D	H
17	C	C
18	B	G
19	C	D
20	A	M

3.1.2 Dependent variables

Using Integrate, two researchers performed the manual selection of landmarks (called point picking) on the scans of the calibration object. A total of 200 landmarks (20 scans x 10 landmarks) were identified by each researcher. The landmarks were set at the center of the washers on the sides of the bottom box of the calibration object.

Integrate's point picking mode was activated with centroid as the pick mode. This means that Integrate calculated the average Cartesian co-ordinates of all points in the pick region (the points within the cursor domain). The point closest to this calculated average was selected. The cursor (consisting of four small blue dots) was centerd in the washer. Researchers picked points on scans in the same order that the scans were made. From every scan, 10 landmarks were selected. The order for selecting landmarks was:

1) Front view - left lower washer
2) Front view - right lower washer
3) Front view - right upper washer
4) Right view - left lower washer
5) Right view - right lower washer
6) Back view - left lower washer
7) Back view - right lower washer
8) Back view - right upper washer
9) Left view - left lower washer
10) Left view - right lower washer

We derived several distances from the landmarks. Six distances were calculated in order to determine the accuracy within a scanning head. The distance between the centers of the lowermost white washers on each side of the lower box was determined from the landmarks. Moreover, the vertical distance was determined on the right edge of the front and back sides of the lower box. The derived distances were:

a) Distance between front left lower washer and front right lower washer
b) Distance between front right lower washer and front right upper washer
c) Distance between right left lower washer and right right lower washer
d) Distance between back left lower washer and back right lower washer
e) Distance between back right lower washer and back right upper washer
f) Distance between left left lower washer and left right lower washer.

3.2 Results

3.2.1 Absolute and relative errors

The error in the results was quantified in two ways:

a) The difference between the manually determined distance between the washers and the data from the landmark files (absolute error). We assumed that the manual measurement was correct. The absolute error is shown in Figure 5.

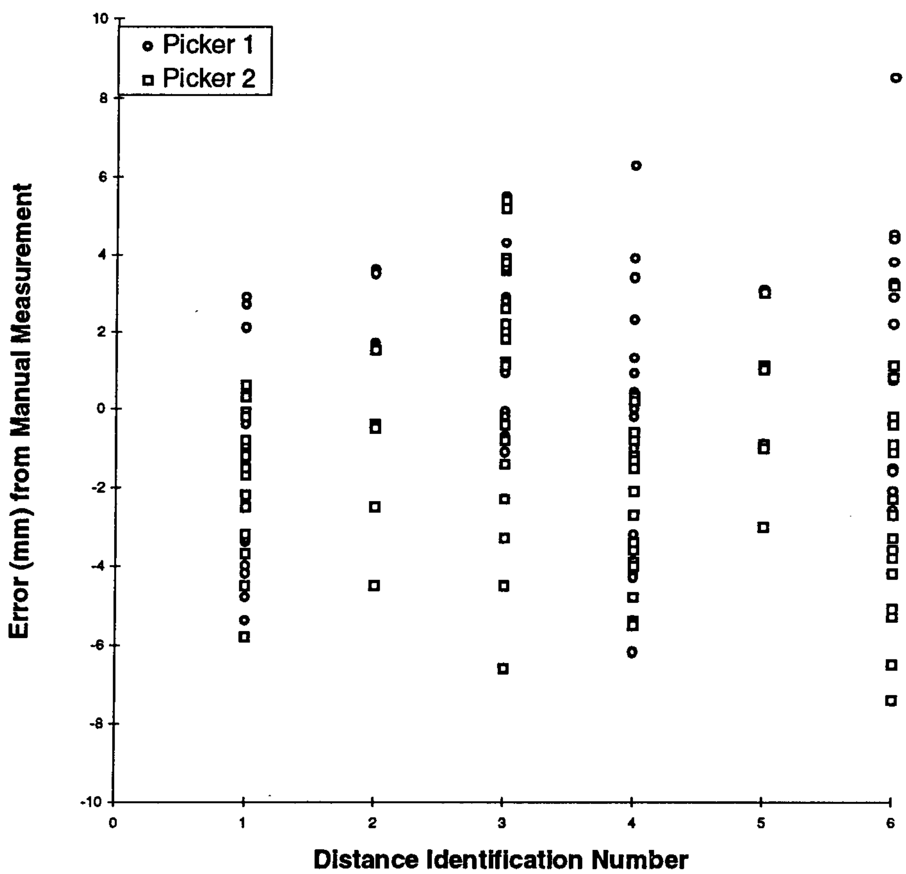

Figure 5: Absolute errors (in mm) from the manually determined measurements to the measurements determined by point picking in Integrate.

Figure 5 indicates that the errors were not systematic between scanning heads, but were simply random errors. Note the discrete steps for the vertical distances (distance identification number 2 and 5). The two-mm steps reflect the distance between the scanning lines. The error was smaller for the vertical distances than for the horizontal distances.

b) The difference between the individual distances between the landmarks and the average difference (relative error); it is assumed that the average of all calculated distances is a perfect estimator of the real distance. In Figure 6, the relative errors in the distance are shown for each distance for both researchers.

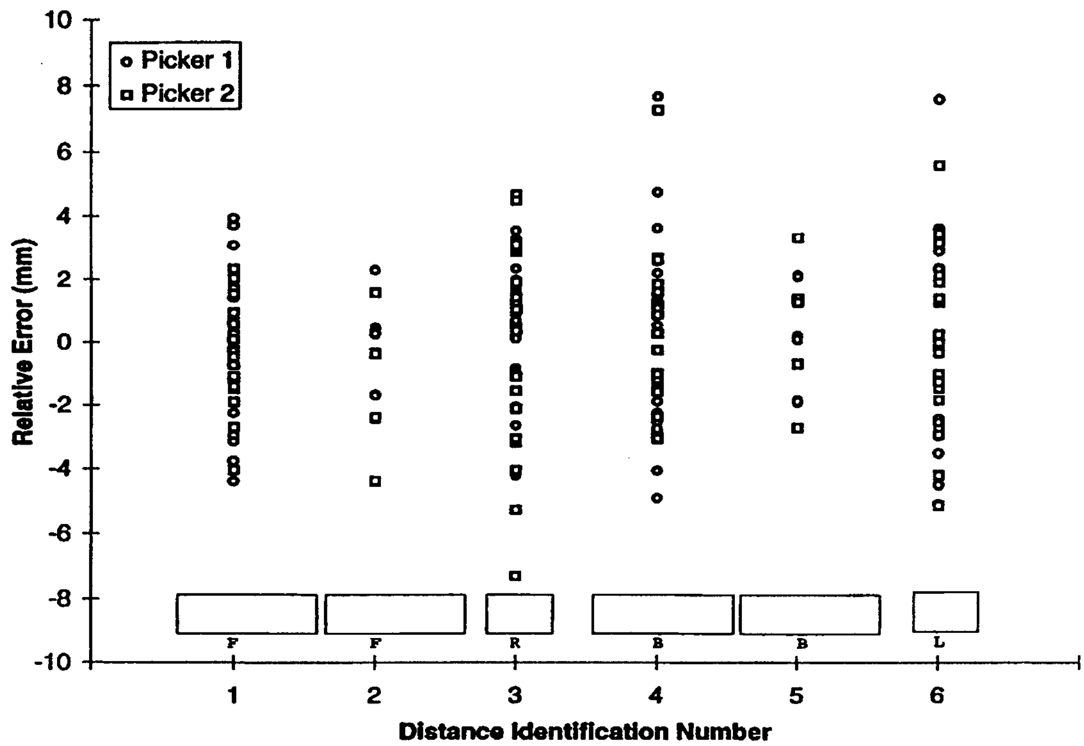

Figure 6: Relative errors (in mm) for the six determined distances.

3.2.2 Error sources

The errors can be attributed to three main categories:

a) Resolution errors. Point-picking in Integrate chooses the closest point of the scan to the placement of the cursor. Sometimes the researcher picking points could see that the desired location (i.e. the center of the cursor) was not the point where Integrate put the landmark. Researchers created a simulation program to determine the error due to this shift. Five thousand randomly generated points were relocated to the scanned points. The mean error was 1.21 mm, with a standard deviation of 0.43 mm (range 0.048 - 2.062). This means that in estimating the distance, the error may be up to two times 2.062 mm, which is approximately 4.12 mm. For the relative errors, 92% of all picked points were within this range. For the absolute errors, approximately 88% were inside this range. This means that 88% of the error can be attributed to resolution errors. We estimate that accuracy can be improved by 90% (to ± 0.5 mm) by using software that estimates a surface point between scanned points.

b) Point-picking errors. The remaining 8% of the relative errors may be due to point-picking errors. Sometimes a desired spot for landmarking was not available because there were no points in that area of the scan. This may also have caused the relatively small amount of large errors.

c) Errors related to the scanner software and hardware. Considering the errors mentioned above, it is impossible to attribute errors to the scanner hardware and software.

Though colored dots were not used as landmarks in the study, relying on color information in the scans could introduce an additional error source: color resolution. The color resolution of a whole body scan is approximately 1,000 (vertical) x 256 (horizontal) pixels. This means that each pixel is about 2 x 4 mm (assuming a circumference of one meter). When the color is shown on top of the body surface, the dots are interpolated, thus showing a smooth image. If the colored landmarks were larger than 4 mm, the error in picking the center of the dot would be very small.

3.2.3 Influence of location on error

We analyzed the data in DesignEase to determine the influence of position on error measurement. The model with the highest Whitcomb score was chosen, and in all cases this was a linear model. Analysis of variance showed all of the models to be insignificant for explaining variation in the errors. Additionally, analysis of variance in SYSTAT module MGLH confirmed that neither the vertical nor the horizontal position of the calibration object influenced the error. This means that there was no systematic error present in the scan volume that was due to the position of the calibration object. Although there were some measurement errors present, they could all be attributed to random error, including human fallibility.

3.2.4 Learning effects in point-picking

The residuals plotted against run order for both researchers who picked points showed no evidence of a learning curve effect.

3.2.5 Differences between two point-picking researchers

Of all the points picked by the two researchers, 52% were identical. There was, however, a noticeable difference between the two researchers concerning the measured distances. The first researcher overestimated the absolute distance by 0.53 mm on average. The second researcher underestimated the actual distance by 1.1 mm on average. There was a large discrepancy (over 3 mm) between the researchers' measurements for the distance on the left side of the box, which was scanned mostly by Head 3. The overall standard deviation in the error was similar for both researchers, at approximately 2.6 mm (Table 4).

Table 4: Absolute errors for both point-picking researchers. The values are the differences between the picked values and the manual values.

	front horizontal	front vertical	right side	back horizontal	back vertical	left side	average
Mean for Picker 1	-1.31	1.24	2.22	-.91	.92	1.00	.53
Mean for Picker 2	-1.58	-.38	.84	-2.63	-.49	-2.33	-1.09
S.D. for Picker 1	2.52	1.18	2.25	3.39	1.53	3.17	2.72
S.D. for Picker 2	1.80	1.89	3.27	1.97	1.58	2.74	2.54

3.2.6 Errors between opposite scanning heads

Unlike the distances between the washers, the exact dimensions of the box were known. Therefore, the distance between the opposite sides of the scanned calibration object were calculated. We rotated the lower calibration box in the top view so that one side was exactly aligned to the horizontal screen axis. Then, the object was translated to the other side and the distance was measured. The width was 501.3 ± 2.8 mm, the height 102.1 ± 1.4 mm, and the depth 199.8 ± 1.9 mm.

Using the inside of the washers to determine the dimensions of the box was not a good method; it overestimated the real values by approximately 6 mm, due to the placement of the landmarks on the washers. The distances in the previous sections, however, were not influenced by this stand-off (cosine error). We concluded that the dimensions as measured from the scans are close to the real dimensions of the box, so that scanner distortion is within the specified range.

4.0 CONDITION 2: ALIGNMENT DETERMINATION OF NEIGHBOURING HEADS

4.1 Methods

The first test condition revealed that scanner error was independent of the scanned object's location in the scanning space. Therefore, the calibration object was placed in only one location in the second test condition. The calibration object was fixed to the pole by a collar at a height of 1,010 mm above the floor (position C in Table 1) and located on the platform at horizontal position M. The front of the calibration object was oriented in four different ways: facing between heads 0 and 1, 1 and 2, 2 and 3, and 3 and 0.

The scans were separately merged for each scanning head by Cyberware's CyPie program. This was achieved by supplying the scan data of only one head to the CyPie program with the command *CyPie -c -p,H0.align filename.ply*, in which *H0.align* stands for the alignment file of scanning head 0 and *filename.ply* stands for the scan data of head 0. The alignment file was different for each scanning head. The alignments were:

	global	head 0	head 1	head 2	head 3
angle	0	0	0	0	0
position	0	0	-1000	800	-550
radial	0	0	-300	-200	200
scale	-	1	1	1	1

The combined view (data from all four heads) of each scan was also stored.

4.2 Results

Figure 7 shows a cross-sectional view of the pole of the calibration object for each scanning head and the combined view. It clearly shows that the merging is adequate. The circular shape of the pole is well represented in the scan.

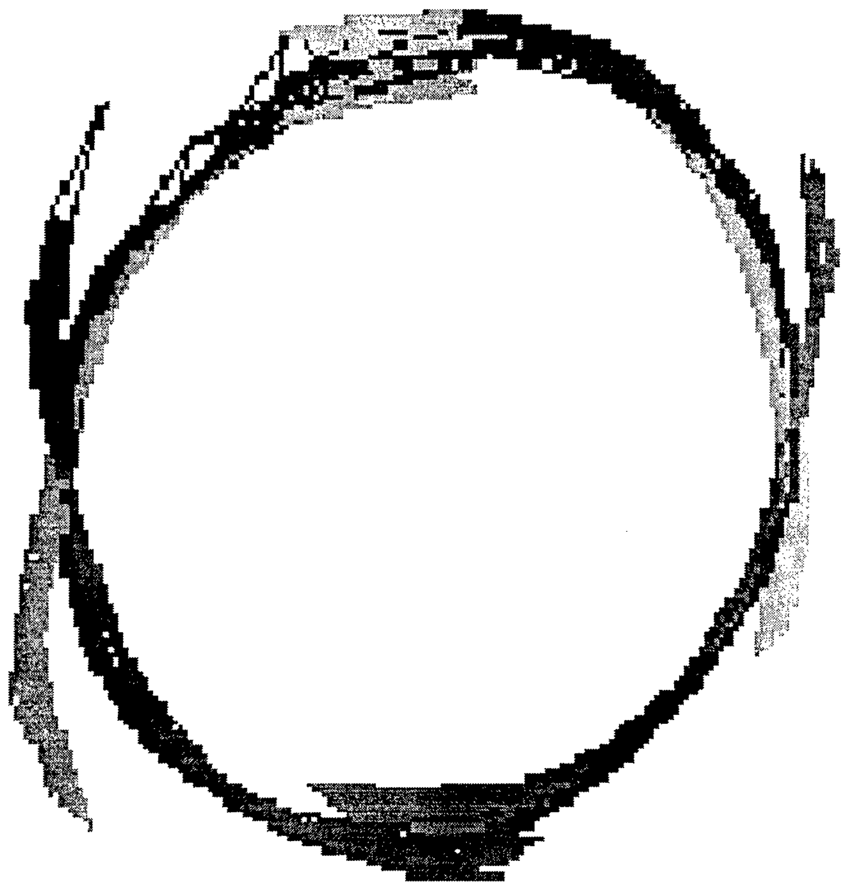

Figure 7: Cross-sectional view of pole of the calibration object for each scanning head and for the merged view.

5.0 CONDITION 3: ANGLE BETWEEN SCANNING HEAD AND CALIBRATION OBJECT

5.1 Methods

In order to determine if the error in point-picking was related to the angle between the head and the object, we scanned the calibration object at height C in position M. Seven scans were made: with the front of the calibration facing head 0 (0 degrees) and rotated 15, 30, 45, 60, 75, and 90 degrees counterclockwise. The separate scans were merged by CyPie, but separately stored for each head. The combined view of each scan (data from all four heads) was also stored.

The yellow dot point picking was done by one researcher only. The number of identified landmarks was 126 [7 angles x 6 (four heads + front + back) x 3 landmarks]. However, in five scans, landmarks could not be detected, leaving a total of 111 landmarks (37 x 3).

5.2 Results

The relative error did not appear to depend on the angle of the scanner head to the scanning object (Figure 8).

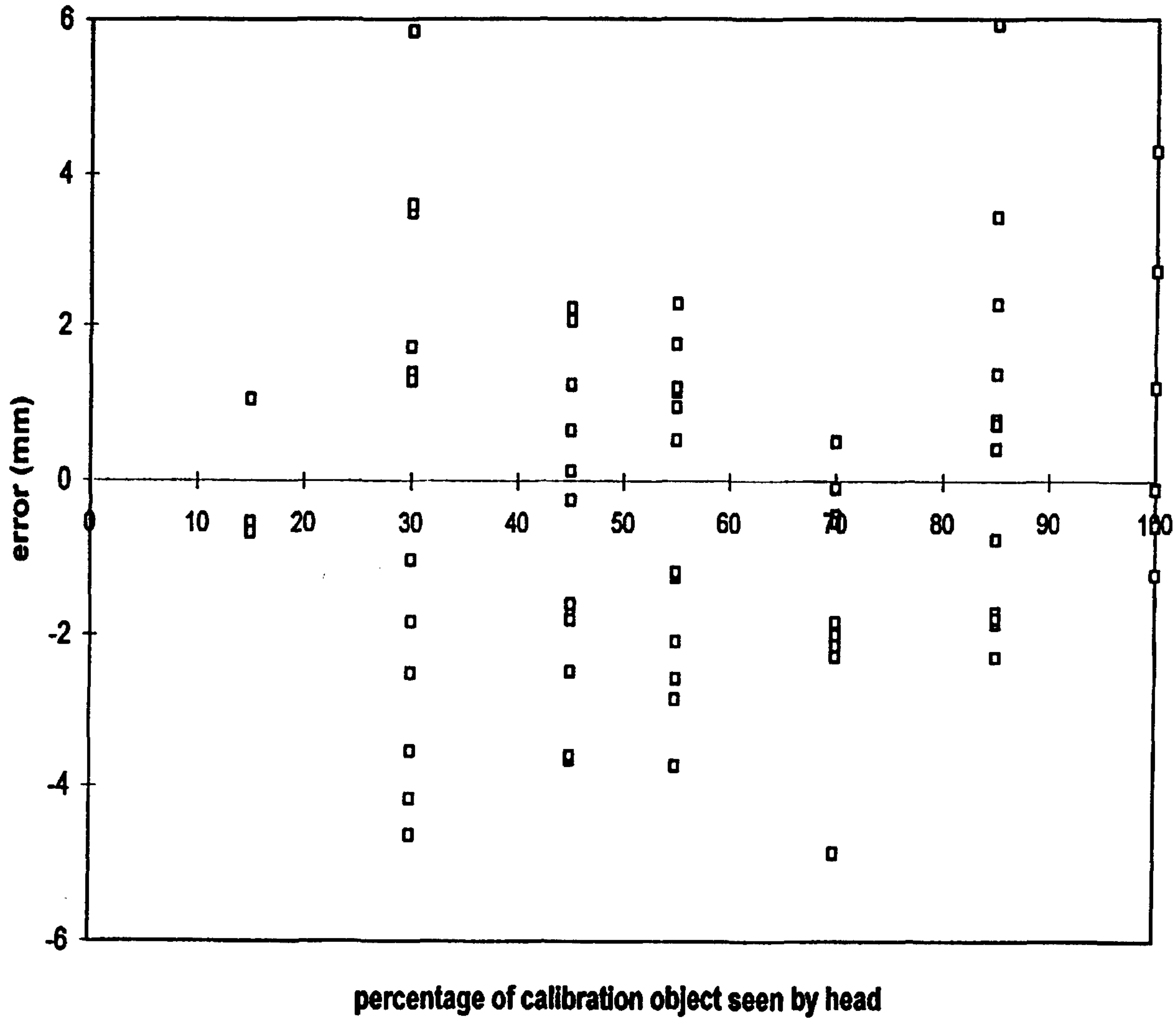

Figure 8: Relative error (mm) in point picking related to the percentage of the object that can be seen by the head.

We expected the error to increase when the head could see less of the calibration object. This was not the case, and we concluded that landmarking can be done accurately even when the scanned object sits at a sharp angle to the scanner head.

6.0 GENERAL DISCUSSION AND RECOMMENDATIONS

6.1 Resolution Errors

The first test condition shows that the resolution of the scanner (5 mm between points horizontally, 2 mm between lines vertically, and 0.5 mm in the depth values) can lead to errors in point picking. The desired point for a landmark is often not available. This may be frustrating for researchers picking points.

We solved this problem by creating a new Integrate pickmode which calculates the indicated landmark position instead of choosing the point closest to the cursor. When picking points with Integrate, researchers had to remember that:

- They should be careful with choosing the pickmode. The pickmode "closest" yields unexpected results when picking on flat surfaces with a large eye distance.
- The error due to resolution depends on the direction in which the distance is measured.

6.2 Reflections

Occasionally, errors in point picking can occur because shiny objects are seen closer to the scanner head than they actually are. An example of such erroneous data points is shown in Figure 9. Researchers picking points should be aware of this risk, and should change views to make sure that points were picked in the correct region. Moreover, the occurrence of reflections should be prevented by using non-reflective markers and removing subjects' jewelry and watches before scanning. Another possible solution is to set the sensitivity of each head in the CyScan software before scanning.

The sensitivity of the whole body scanner can be controlled by Cyberware software. To adjust the sensitivity, minimize the CyScan window. At the wbscan prompt, type the following command:

```
source /app/fbs/unzippered/sensxx
```

in which sensxx stands for the filename of the sensitivity settings. Sensitivity ranges from sens30 to sens80, and a standard setting for human body scanning (sensstand). The maximum sensitivity is 100 and the minimum is 0.

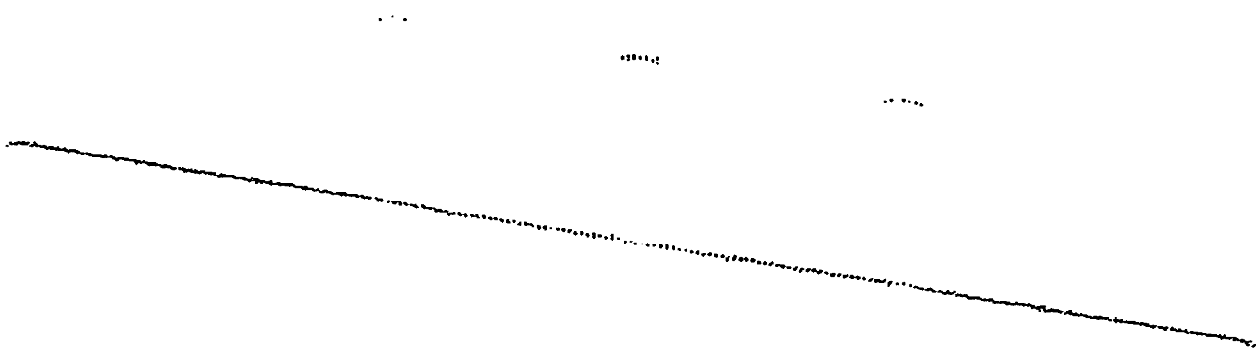

Figure 9: Top view of the back of the calibration object. Note the three areas separated 71 mm from the box. These are the reflections of the yellow dots on the box.

6.3 Alignment File

At this writing, we do not know exactly what the values in the Cyberware alignment file represent. Nevertheless, it is important to know how a change in these parameters affects the scans. We compared the results of the alignment file in paragraph 2.5 to the results in paragraph 4.1. Therefore, the calibration object was scanned with both alignment files.

Figure 10 shows the results for the cylinder. Better results were achieved with the alignment file described in paragraph 4.1. The differences between the alignment files are almost invisible on the box, since merging differences are only visible at the edges. Figure 10 emphasizes the importance of accurate calibration.

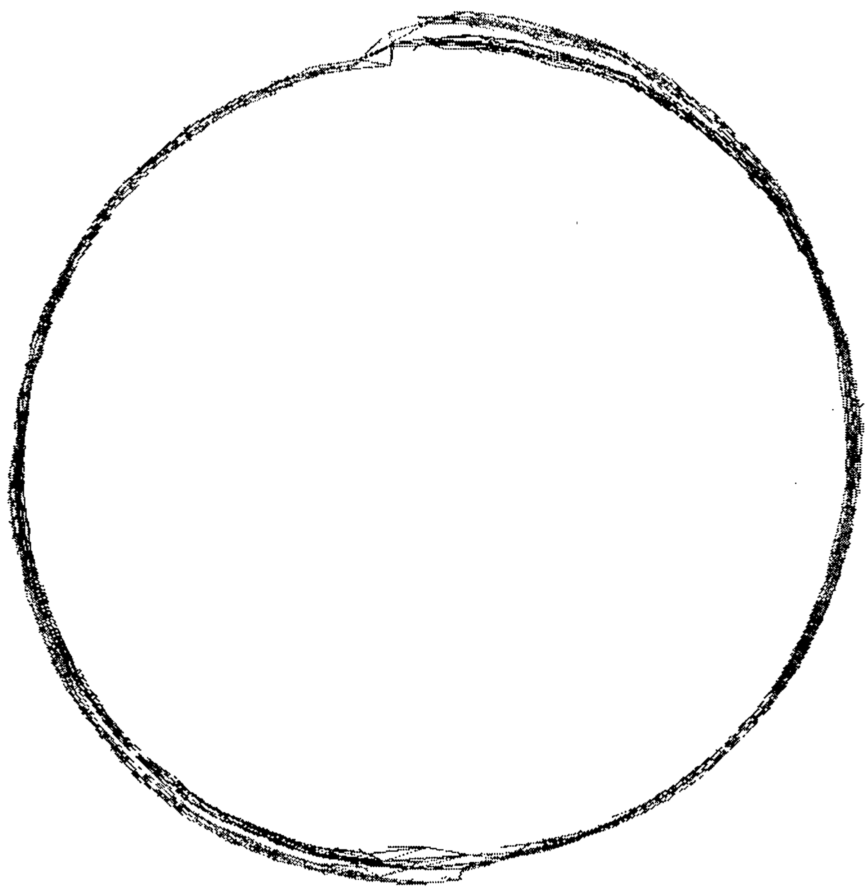

Figure 10: Top view of the cylinder of the calibration object for two different alignment files.

When the calibration object was scanned twice with the same alignment file, the differences between the two scans were very small (less than 0.5 mm). However, when an object is resampled in order to convert it to a movie.byu format, the errors increase at horizontal edges. The resampling technique calculates the intersection of beams from the vertical central axis with the surface of the object. On horizontal surfaces, differences of over 10 mm occur between the points of the two scans. On vertical surfaces, however, the difference is usually within 1 mm.

6.4 Calibration Procedure

In this study, the focus was on analysis of the input and output of the whole body scanner. We treated the scanner as a black box and compared the input (calibration object) and the output (scans). The procedures described in this report can be used as an indicator if the scanner produces accurate results.

When a well-defined calibration procedure is performed on a regular basis, there is a better chance for accurate results to be gathered.

The basal calibration procedure is performed by Cyberware. A small object is located on a well-defined spot in the scanning space, and the data-acquisition software is adjusted for that point. According to Cyberware, this procedure is only necessary upon installation and after major changes in the hardware.

Calibrating the alignment of the scanning heads by changing the alignment file is recommended after installation and after relocation of the scanner. If the scanner stays at a fixed location, Cyberware recommends calibrating the scanner at regular intervals (every three months). This calibration procedure can be done with a folded sheet of paper (Burnsides, 1996). The resulting alignment matrix should be stored on disk and linked to the data of each experiment.

After the calibration, the scanner operator should make some checks before collecting data:

1. Check the alignment of the color and depth-shading information. The calibration object can be used for this purpose. The standard deviation of the difference between the landmarks in RGB view and in depth shading view should not exceed 2 mm.

2. Check if each head yields the right distances. Test condition 1 showed that the location of the object in space was not important. Therefore, the object can be located in the center of the platform. The standard deviation of the error should be within 2 mm.

3. Check if the merging procedure works correctly. Compare the scans from individual heads to the merged scan of the calibration object. If the object is distorted, the scanner should be recalibrated. Another way to check merging is by determining the distance between front/back and left/right from the top view of the calibration object. The distances should be within 497 - 503 mm and 197 - 203 mm.

7.0 CONCLUSIONS

• The size of the calibration object (500 x 200 x 100 mm) was very well reproduced in scans made by the Cyberware WB4 scanner (501.3 x 199.8 x 102.1 mm). We determined that no systematic distortion occurred. This conclusion is supported by the finding that the absolute mean error in point picking did not exceed 2 mm.

• When landmarks have to be determined on a scan, the detected point may be 2.06 mm from the desired point due to the resolution of the scan. In determining linear distances, the possible error doubles to 4.12 mm. Approximately 90 percent of the study's point picking error was within the range of -4.12 to 4.12 mm. The larger errors may have been caused by human error during point picking or by missing points in the scan.

• Over 50 percent of the points picked were identical between the point-picking researchers.

• Point-picking error was independent of the vertical and horizontal location of the calibration object in the scanning space.

• Point-picking error was less in the vertical direction than in the horizontal direction, probably because the scanner's vertical resolution (2 mm) is better than its horizontal resolution (5 mm).

• We estimate that accuracy can be improved by 90% (to ± 0.5 mm) by using software that estimates a surface point between scanned points.

• The merging procedure (CyPie) calculates a good optimum out of the scans for each scanner head.

• Landmarking can be done accurately even when the scanned object sits at a sharp angle to the scanner head.

• The alignment file (best.align) should be checked regularly to prevent scanning distortion.

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