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Vicon System Precision Analysis at US Army Combat Capabilities Development Command Army Research Laboratory

by Arnon M Hurwitz and James Dotterweich

NOTICES

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14. ABSTRACT
This report details the findings derived from data taken from the Vicon motion-detection system at the Autonomous Systems Division of the US Army Combat Capabilities Development Command Army Research Laboratory. This exercise was undertaken primarily to obtain an understanding of Vicon precision.

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Summary

This report details the findings derived from data taken from the Vicon motion-capture system at the Autonomous Systems Division of the Combat Capabilities Development Command, Army Research Laboratory. This exercise was undertaken primarily to obtain an understanding of Vicon precision. After many repeat measurements, the conclusion obtained is that the Vicon "repeat measure" (precision plus bias) will give readings that are up to approximately 1.0 mm out of true for the distances considered (119.53 and 239.08 mm).

1. Introduction

This report details the findings derived from data collected using the Vicon motion-detection system at the Autonomous Systems Division of the US Army Combat Capabilities Development Command Army Research Laboratory (CCDC ARL).

The CCDC ARL Vicon system is a roughly 50- × 30- × 22-ft cuboid space enclosed by a truss system that holds 30 near-IR cameras that together can detect and record the position and motion paths of small markers affixed to objects within the space (e.g., robots or humans) and which we term the "Vicon Space". The interest here is in the precision and bias of short-distance Vicon measurements. Note that distances were measured in a restricted part of the Vicon space and only along the floor of that space.

2. Methods, Assumptions, and Procedures

As explained in the following, the observations were derived from repeated measurements of known distances on the Vicon "Wand" artifact placed on the floor of the Vicon Space. These measurements were not true replications, as the Wand was not measured, relocated, and later remeasured at the same original locations, so the variation introduced by relocation is not present. In addition, the Wand was not positioned at any level above the floor. The results reported here should thus be taken as a best-case scenario for Vicon performance.

The Vicon has an object tracking and smoothing filter feature that adjusts measured distances of markers to equal known values at various locations in its measurement space to compensate for spatial distortion effects on a tracked object. This feature was turned off for the current experiment in order to examine actual rather than compensated measurements produced by the system; otherwise, there would be little to no observed variance in the repeated measurements. (For a more exact statement of the Vicon object tracking filter method, see Appendix A). This filter can be turned on for object tracking needs, but in understanding Vicon marker location fixes from raw readings, it was turned off for these experiments.

This exercise was undertaken primarily to obtain an understanding of Vicon precision plus bias for an upcoming experiment involving the arm movement of the RoMan4 autonomous platform. It was conjectured that this precision would lie in the 1- to 2-mm range.

2.1 Vicon Wand

The Vicon system consists of an array of many near-IR cameras positioned to optimally cover the cuboid capture volume located at CCDC ARL. The artifact that provides the known measured distances for this experiment is called the Wand, and a 2-D view of it is shown in Fig. 1.

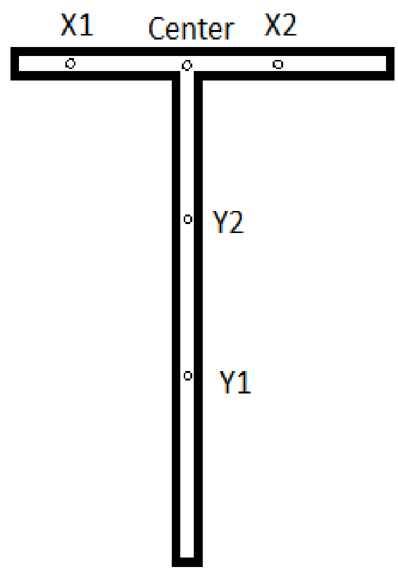

Fig. 1 Vicon Wand

Each labeled point on the Wand in Fig. 1 has an (x, y, z) expression of location. For example, the (x, y, z) expression at Y1 in Fig. 1 is labelled (Y_x1, Y_y1, Y_z1). The origin location is labelled (X_or, Y_or, Z_or).

The distance between X1 and X2 is given as 239.08 mm, and the distance between Y1 and Y2 is given as 119.53 mm. All points lie on the same z-plane.

Note: All measurements quoted in the following are given in millimeters unless otherwise indicated.

2.2 Vicon Space

Figure 2 shows the 30- × 50-ft Vicon floor space and how the Wand was moved around to five different random spots on the floor. Three Vicon cameras on tripods were also included to give closer focus. The experiment was confined to a 12- × 8-ft restricted space on the floor where the future RoMan4 experiment is planned to be run. All Vicon measurements on the X and Y markers of the Wand were taken with reference to an origin point, which was the center point of the Wand in the location at bottom right of the space, as shown in Fig. 2. Everything is relative to the “origin” location. Vicon treats this as the (0, 0, 0) point, so where it was exactly in the Vicon Space or in the building does not make a difference to the final test outcome.

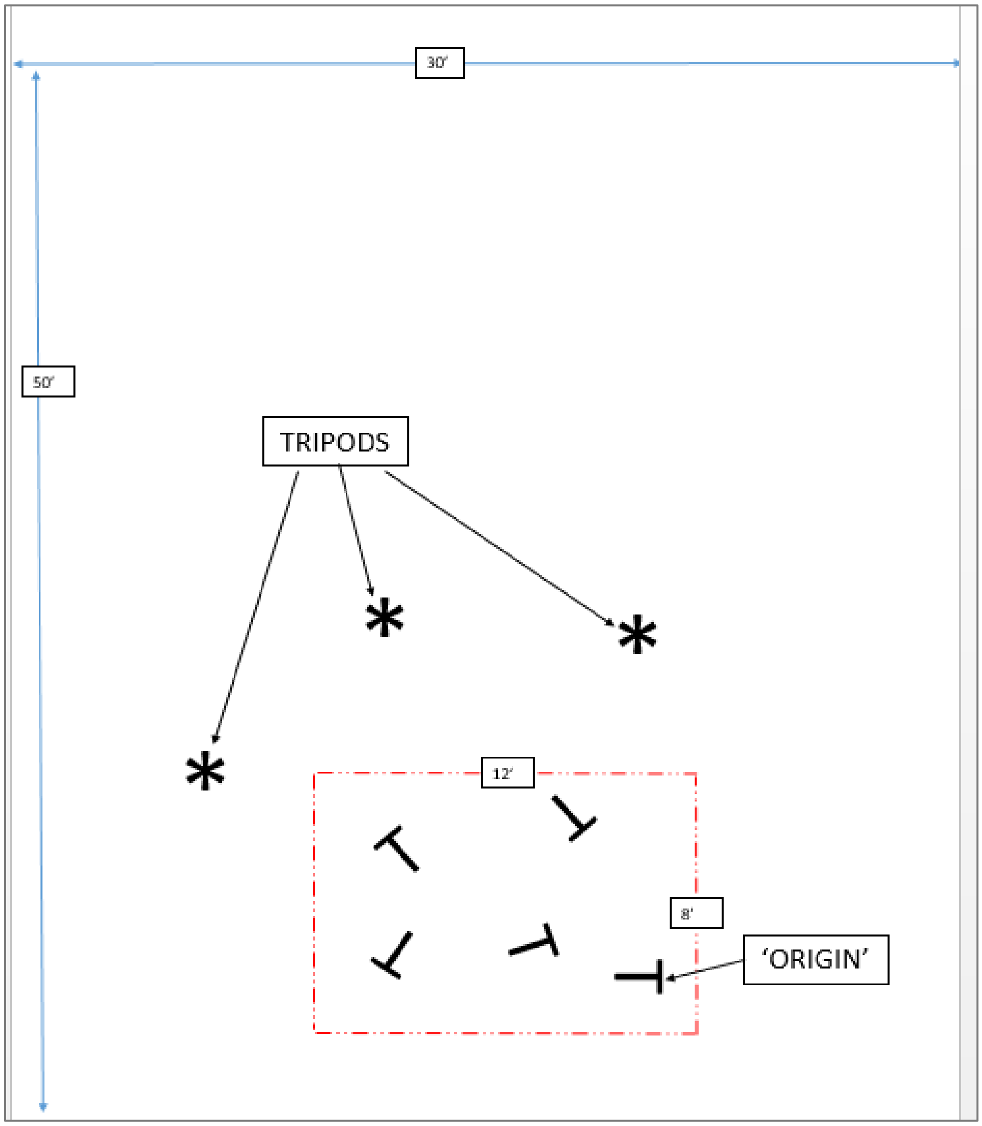

Fig. 2 Vicon Space (floor) and the Wand locations for the experiment (locations are approximate)

2.3 Data

The system scanned all five labelled points on the Vicon Space where the Wand was placed. Each scan consisted of 500–600 frames, each of which lasted approximately 0.1 s. The scan was repeated three times at each spot, resulting in 15 sets of readouts. Each readout contained an average of 581.8 frames, producing 8727 rows of data.

3. Results and Discussion

Data summaries are shown in the following. For the complete data set, please contact the authors.

Table 1 shows the first and last rows of the raw data.

Table 1 First and last rows of the raw Vicon scan data (last column added as spot/scan label)

row	Frame	X_or	Y_or	Z_or	X_x1	Y_x1	Z_x1	X_y1	Y_y1	Z_y1	X_x2	Y_x2	Z_x2	X_y2	Y_y2	Z_y2	Vdata
1	1	8.703	8.511	25.073	168.735	8.479	24.211	8.872	249.086	24.732	-71.282	7.612	24.003	8.903	128.617	24.531	1
8727	583	1240.95	2844.93	24.798	1385.96	2777.75	23.831	1341.85	3062.86	25.037	1168.46	2878.57	24.62	1291.19	2953.65	24.48	15

The bottom column of Table 1 gives a label (Vdata) for each spot scan. So Vdata = 1 refers to spot1_scan1, Vdata = 2 refers to spot1_scan_2, Vdata = 15 refers to spot5_scan3, and so on. All means and standard deviations for both the X1-X2 and the Y1-Y2 measurements are given in Table 2. (Note that the center location is ignored in the analysis).

Table 2 Means and standard deviations for X1-X2 and Y1-Y2 distances

	spot1_1	spot1_2	spot1_3	spot2_1	spot2_2	spot2_3	spot3_1	spot3_2	spot3_3	spot4_1	spot4_2	spot4_3	spot5_1	spot5_2	spot5_3
Distance X1 to X2	239.9	239.9	240.0	239.5	239.5	239.5	240.1	240.1	239.5	239.7	239.7	239.7	239.7	239.8	239.8
StdDev X1 to X2	0.084	0.128	0.135	0.017	0.018	0.017	0.033	0.035	0.017	0.050	0.043	0.043	0.022	0.021	0.023
Distance Y1 to Y2	120.6	120.5	120.5	120.3	120.3	120.3	120.2	120.2	120.3	119.9	119.9	119.9	120.4	120.4	120.4
StdDev Y1 to Y2	0.083	0.055	0.052	0.014	0.013	0.013	0.012	0.013	0.014	0.049	0.044	0.044	0.018	0.019	0.017

Figure 3 shows these values plotted out. (The X-axis ticks are the Vdata labels of Table 1).

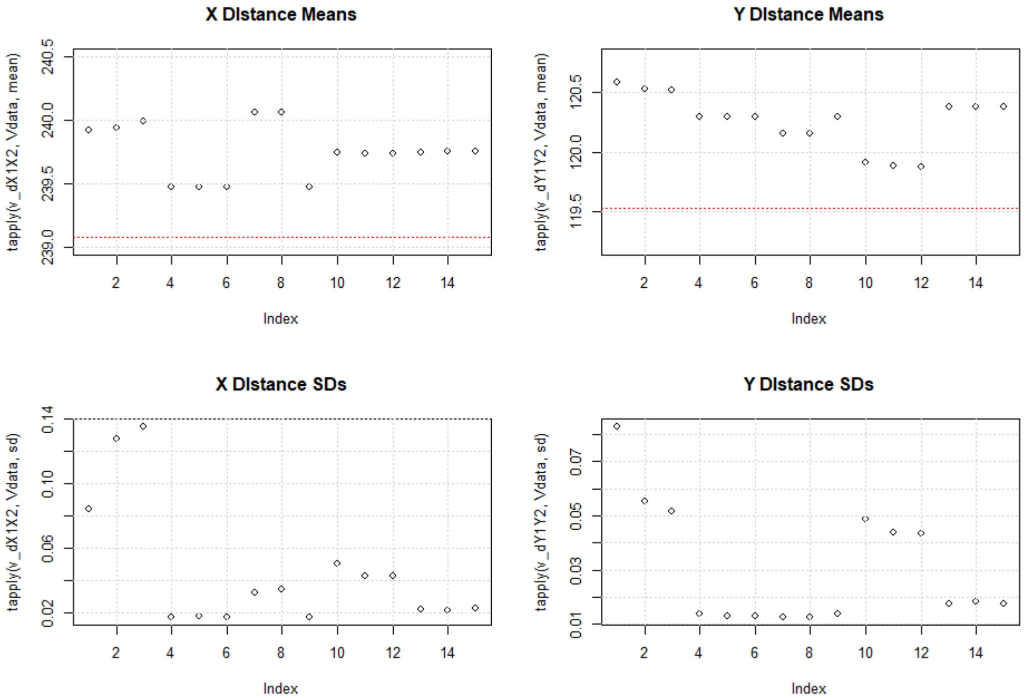

Fig. 3 Means and standard deviations for X1-X2 and Y1-Y2 distance measures in millimeters. Note that the dotted horizontal lines in the Means plots indicate the true values of 239.08 and 119.53 mm, respectively.

As expected, the scans cluster in groups of three (due to the three runs at the same location) except for the X Distance Means at x-axis Location 9. (This anomaly is, however, included in the analysis; only the X-mean estimate is slightly affected.)

Figure 4 is a typical histogram of distance-measure points for the spot1_scan3 data subset.

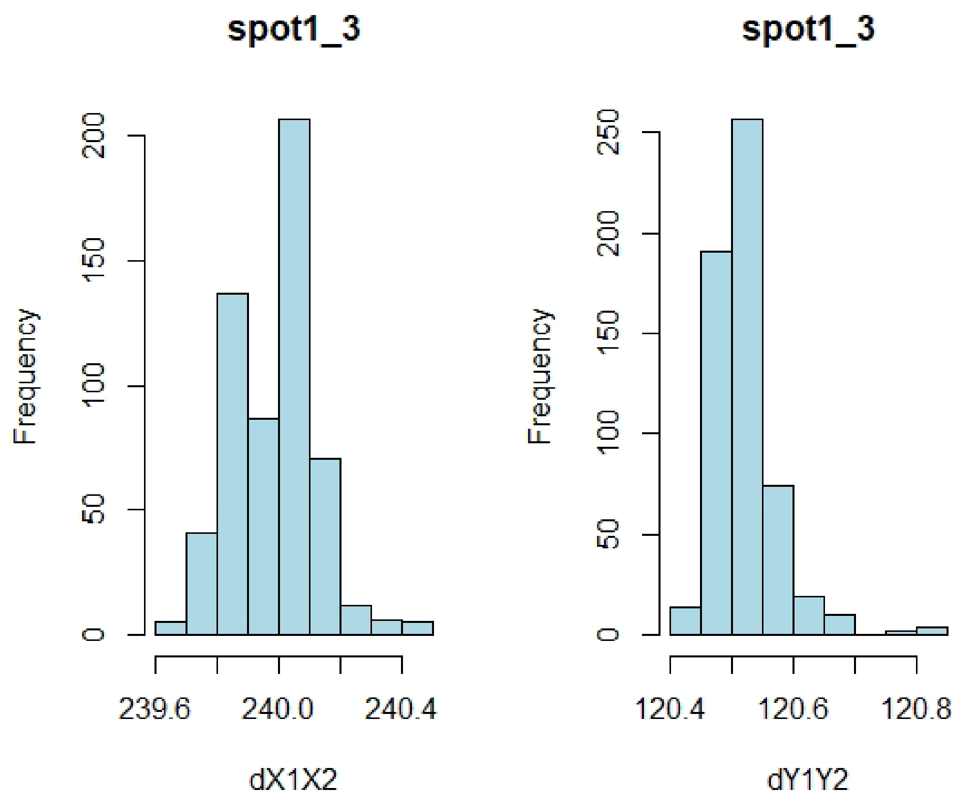

Fig. 4 Typical scatter of distance measurements in millimeters at spot-1/scan-3 data subset. True value for dX1X2 = 239.08 mm; true value for dY1Y2 = 119.53 mm.

The distributions in Fig. 4 were found to be non-Normal (non-"Gaussian") using the Shapiro–Wilk test. The usual (+ 3x standard deviation) upper range limit above the mean bias (based on Normal-distribution theory; see Appendix B) will thus only be approximately accurate. Computing the overall observed imprecision values using this (average bias + 3x pooled standard deviations) method we obtain Table 3.

Table 3 Observed Vicon imprecision using the 3x standard deviation method (standard deviations are pooled values; all readings in millimeters)

DISTANCE	TRUE VALUE	OBSERVED AVE	BIAS	STD.DEV	3xSD	BIAS + 3xSD
X1 to X2	239.08	239.76	0.68	0.177	0.531	1.211
Y1 to Y2	119.53	120.26	0.73	0.118	0.354	1.084

Estimating the overall imprecision by examining the range on the vertical axes of the X-distance and the Y-distance mean plots of Fig. 3, we come close to the same conclusion that, from Fig. 3, the upper range of the differences are on the order of 1.0 mm. We conclude that the spread of the distance deltas are therefore about 3 standard deviations above the average bias.

4. Conclusions

Two distances on the Vicon Wand were repeatedly measured by the Vicon system, and the overall observed average distances came to 239.76 mm for the X-distance and 120.26 mm for the Y-distance. When compared with the manufacturer-specified wand distances of 239.08 and 119.53 mm, the Vicon thus gave, on average, a small positive bias in both cases. The biases were 0.68 and 0.73 mm, respectively.

Repeat measurements of these two distances gave two pooled estimates of their standard deviations, which were 0.177 and 0.118 mm for X and Y, respectively. The usual (3x standard deviation) is therefore 0.531 mm for the X distance and 0.354 mm for the Y distance. The conclusion here is that the Vicon can be expected give readings that are about 1.0 mm out of true for the range of both distances considered here (see Appendix B).

Appendix A. Vicon Kinematic-Fit Filter System

The Vicon kinematic-fit filter adjusts the Vicon marker positions to be relative to the tracked object. This effectively “smooths out” the individual maker locations by forcing a kinematic fit, fusing it with the actual marker location. The Vicon Nexus software combines the images from the Vicon cameras and fuses them to track individual reflective markers in the Vicon Space. This software can combine markers that are rigidly attached to a physical item, such as sections on a robotic limb, and track the collection of markers as an object. The selected markers are “known”" in the Vicon software as being associated with the other markers on an object by labeling them and tracking their motions.

For each object, the markers are assumed to be rigidly attached to the physical item and thus have set distances between the markers that define an object. The Vicon system can take advantage of this knowledge and smooth the individual marker locations that define an object by forcing a kinematic fit of an individual marker to what its known distance location should be relative to the other markers, for that object. For example, if a marker is not seen well by three or more cameras, its position can still be replicated under the assumption that it is rigidly fixed in position to the other object markers, and the cameras can see at least three other markers that uniquely define the object being tracked by using the kinematic fit filter. This filter, while suitable for object tacking, can cause distortions to the marker locations at times by forcing a fit and smoothing out the marker locations instead of taking the raw feed location of the marker.

This feature was turned off for the current experiment in order to examine actual, not compensated, measurements produced by the system. Otherwise there would be no observed variance in the repeated measurements of the marker position due to the kinematic filter that adjusts measured distances.

Appendix B. A Note Regarding Normal-Distribution Theory

A random variable, x, is said to have a Normal ("Gaussian") distribution with mean μ and variance σ^2—written: $x \sim N(\mu, \sigma^2)$ only if it has a probability density function given by

$$f(x|\mu, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} . \qquad \text{(B-1)}$$

This function produces a symmetric, bell-shaped curve over the x-axis, centered at μ. The symbol σ is called the standard deviation of x.

Approximately 99% of the probability density of x lies within ($\pm 3\sigma$) of its mean μ. Therefore, approximately 99.5% of the probability density of x lies below ($\mu + 3\sigma$), hence the reference to "three times standard deviation" as an upper limit to the expected range of x.

Observed distributions of random variables—usually seen as histograms—are often informally taken as approximately Normally distributed if they appear symmetric and bell-shaped. Many formal tests of Normality exist, such as the well-known Shapiro–Wilk test. Even if a distribution fails a Normality test, it can still serve as a first-pass approximation for purposes of limit estimation if it is reasonably symmetric and approximately bell-shaped.

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