Optotrak Digitizing Probe Development and Accuracy Report

Project Number: 2011RB-029

Revision	Date	Name	Comment
01	4-11-14	D. Beckler	Created

1 Introduction

Motion capture systems are commonly used when studying kinematics of biological structures. A common technique when employing these systems is to establish a desired point within a global frame of reference by using a digitizing probe. The system detects IED markers fastened to the probe thereby determining its geometry and the coordinates of its tip. In any motion capturing system, inaccuracies in determining probe tip location may be expected due to small errors in determining the location of individual markers (Fig 1). This type of error may be decreased by arranging markers into configurations that allow only small translations of probe tip location from inaccuracies of marker position.

In systems which use two or more cameras, errors may also be generated due to marker position discrepancies between cameras. To minimize these errors, a registration is performed which transforms the cameras' local coordinate systems into a single global coordinate system that all cameras can measure against. The quality and reliability of a registration may be affected by many factors including what tool used to register, the length of time a registration is performed, and the volume over which the registration is performed. The purpose of this study was determine how the placement of markers on a digitizing probe affects the errors in determining probe tip coordinates associated with multiple camera motion analysis systems, as well as determine effective techniques for acquiring accurate registrations between multiple cameras.

Figure 1

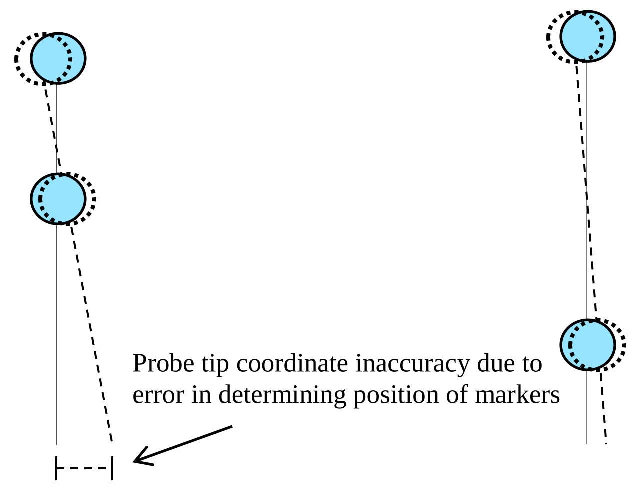
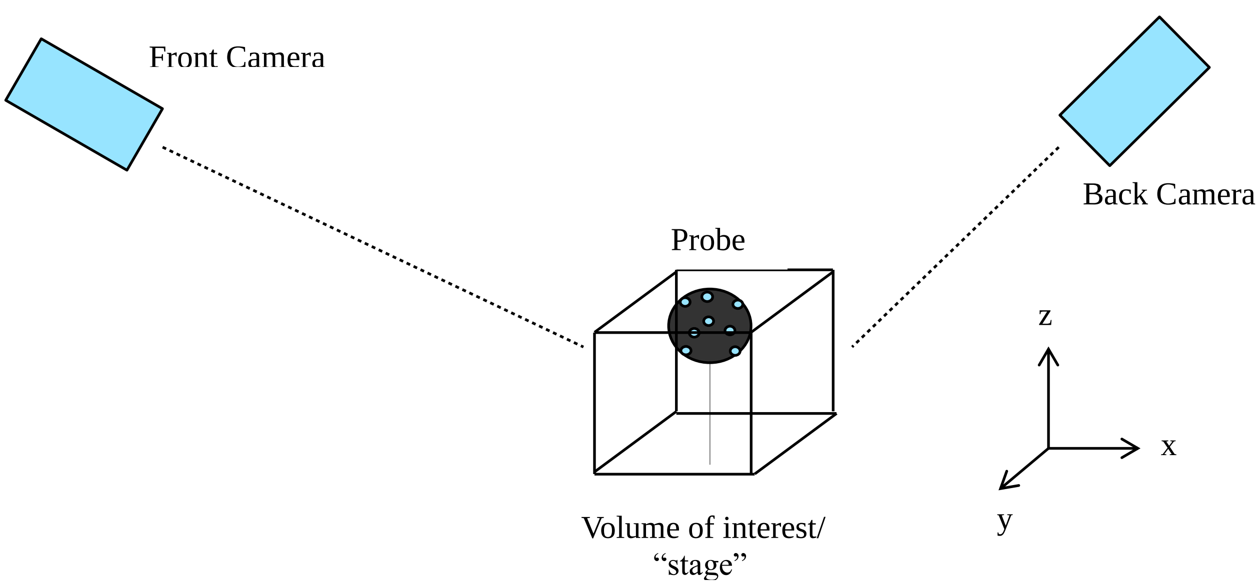


Figure 1: Two similar marker configurations with varying geometries produce different errors in probe tip location

Experimental Analysis

This experiment utilized an NDI Optotrak Certus motion capture system in which two cameras were located at the top of the room, 180 degrees apart, facing each other and angled downward (Fig 2).

Figure 2



Our experimental process consisted of building several different probes in which the markers were fastened into varying configurations. The coordinates of the probe tip for each configuration were determined using two cameras, which served as our control. Probe tip locations were then recorded when a single camera was blocked, switching between the two cameras. The displacement of each coordinate was recorded and the absolute distance was calculated. The absolute distances in probe tip displacement for each configuration under different viewing conditions were compared to determine the accuracy of each different marker configuration. All trials were conducted with registrations that were performed with an NDI cubic reference emitter.

Three configurations were tested with varying dimensions. The first configuration consisted of a sphere at the top of the probe to which eight markers were attached (Fig 3-A). The second configuration was a linear design using two markers where the distance of the markers from the probe tip as well as the spacing between the markers varied (Fig 3-B). The last configuration studied was a cross configuration (Fig 3-C). Multiple trials were conducted with varying dimensions of height and width.

Registration

The accuracy of registrations was determined by first performing the registration and then conducting the aforementioned camera blocking test on a digitizing probe. Registrations were then repeated with varying conditions including what tool was used for registration, the amount of time used to register, and the volume that was registered. All camera blocking trials for the registration testing were done using the same digitizing probe to make sure only the registration was being tested.

The three tools used for registration included the black sphere probe, the steel cross probe, and an NDI cubic reference emitter, a tool marketed by NDI solely for registering multiple cameras. The length of time used for registering varied from 15 to 180 seconds. The last variable tested was the particular volume registered within the field of view of the two cameras. This ranged from the entire volume of the “stage,” or the area between the two cameras where testing would normally occur, where several areas can only be seen by one camera or the other, to a bi-directional volume that could always be seen by both cameras (Figure 4).

Figure 3

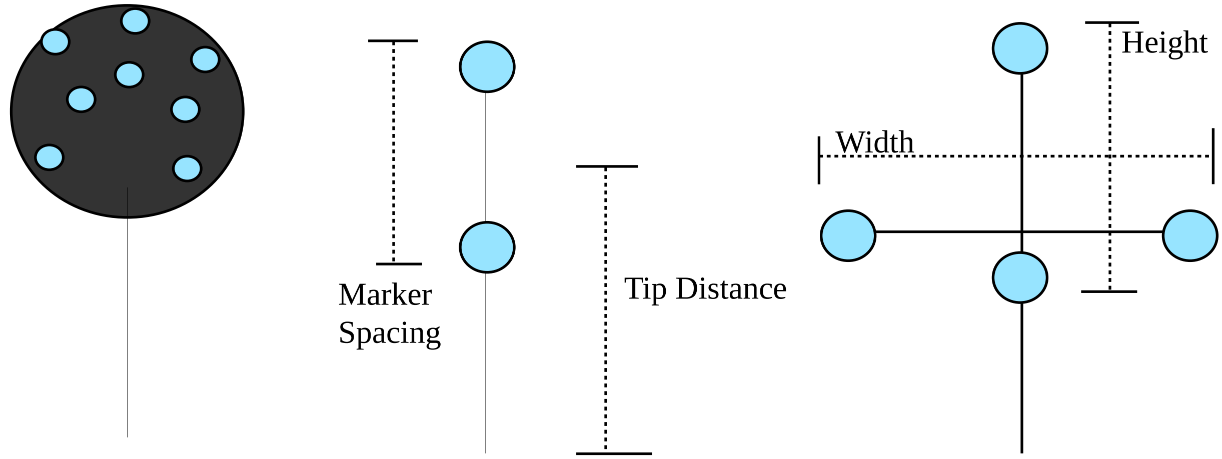


Fig 3-A: Black sphere probe

Fig 3-B: Linear probe with varying tip distance (t.d.) to marker spacing (m.s.) ratio.

Fig 3-C: Cross probe with varying height and width (bottom marker always 7” from tip).

Results

Among the three configurations tested, the smallest errors were seen in the design which incorporated a cross-like pattern of markers, as can be seen in Table 1. Altering the dimensions of the cross configuration also produced noticeable changes in errors of probe tip location associated with varied viewing conditions of the two-camera system. The errors in probe tip coordinates seem to be negatively correlated to the distance between the markers. This trend can also be seen in the linear configurations, though it is less apparent. Once it had been experimentally confirmed that the cross configuration provided the most accurate results, a cross rigid body was constructed from stainless steel allowing for more secure fastening of markers and therefore more accuracy. Follow-up testing confirmed this configuration’s accuracy.

Table 1

Configuration	Dimensions	Min Error	Max Error	Mean Error	STDEV
Sphere	N/A	1.28	3.64	2.46	1.67
Linear R ~ (t.d.) / (m.s.)	5.8” / 9.1” R ~ .63	0.8	2.12	1.45	0.69
	14.1” / 7.5” R ~ 1.96	0.96	2.31	1.63	0.69
	12.1” / 3.3” R ~ 3.73	1.18	2.21	1.64	0.47
Cross (width x height)	10.8” x 4.8”	0.2	0.49	0.35	0.13
	10.8” x 8.9”	0.06	0.19	0.12	0.05
	6.8” x 8.9”	0.07	0.48	0.25	0.18
Steel Cross	10.5” x 8.5”	0.05	0.15	0.1	.04

Table 1: Probe tip errors (in mm) for different marker configurations during the camera blocking test, averaged from all experimental trials.

Registration

Once the accurate digitizing probe had been obtained, more reliable tests could be performed to better understand the methods needed to produce an accurate registration. For registrations performed with the NDI cubic reference emitter, the only method that was viable was covering the entire volume of the stage and collecting points for 180 seconds. Any less time or volume resulted in errors due to insufficient data. The cube registrations produced average errors of 0.2 mm during the camera blocking test with errors of 0.1 mm as a best case scenario, but occasionally producing errors around 0.3 mm. Registrations with the black sphere probe were conducted for 15 – 60 seconds with varying volumes covered. These registrations produced average errors of about 0.3 mm with errors as high as 0.4 mm. Registrations conducted with the steel cross probe ranged in duration from 15 – 180 seconds. Some trials were done covering the entire volume of the stage whereas others collected data only in a bi-directional volume that could always be seen by both cameras. The most accurate trials using this tool occurred when data was collected for 180 seconds. On average, errors were below 0.2 mm with errors occasionally falling below 0.1 mm. A worst case scenario for these trials was about 0.3 mm. Trials in which only a bi-directional volume was registered were susceptible to higher errors when the digitizing probe was positioned in different areas on the stage for the camera blocking test. Registering the entire volume of the stage greatly reduced these deviations. The results are summarized in Table 2.

Figure 4

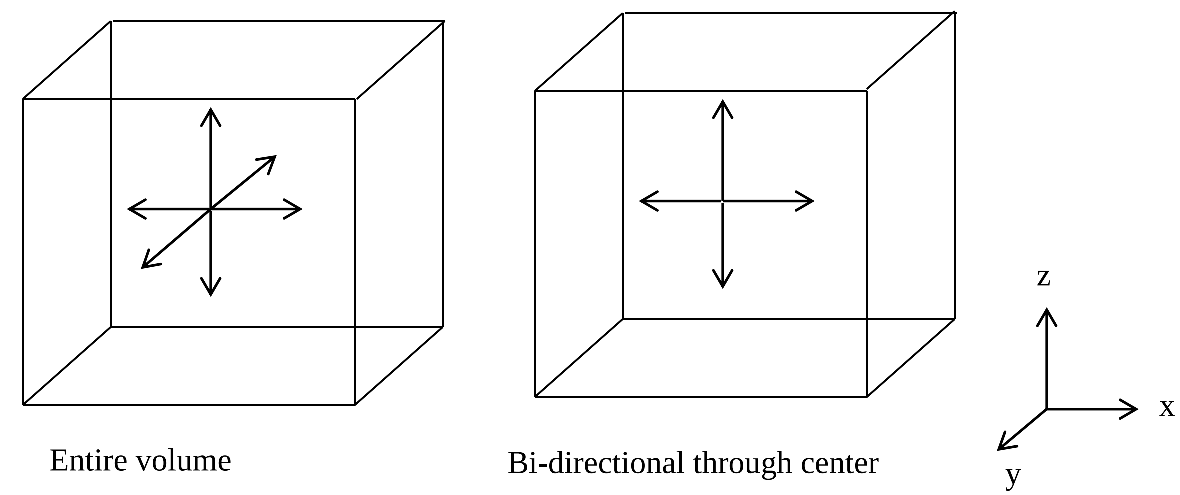


Figure 4: Showing the difference between a registration which covers the entire volume (left) and a registration which covers a bi-directional volume through the center of the stage (right).

Another problem still not understood with camera registrations is that the accuracy of a camera registration decays over time (Figure 5). A registration which provides accurate readings one day will provide considerably less accurate readings only a week or so later. Although a simple re-registration will restore the accuracy, this problem could be troublesome to projects which require several weeks of testing. The first registration may cause errors in one direction while next week's registration may cause errors in the opposite direction. In this way, errors may be compounded and severely distort data. For this reason, the problem merits further experimentation.

Conclusion

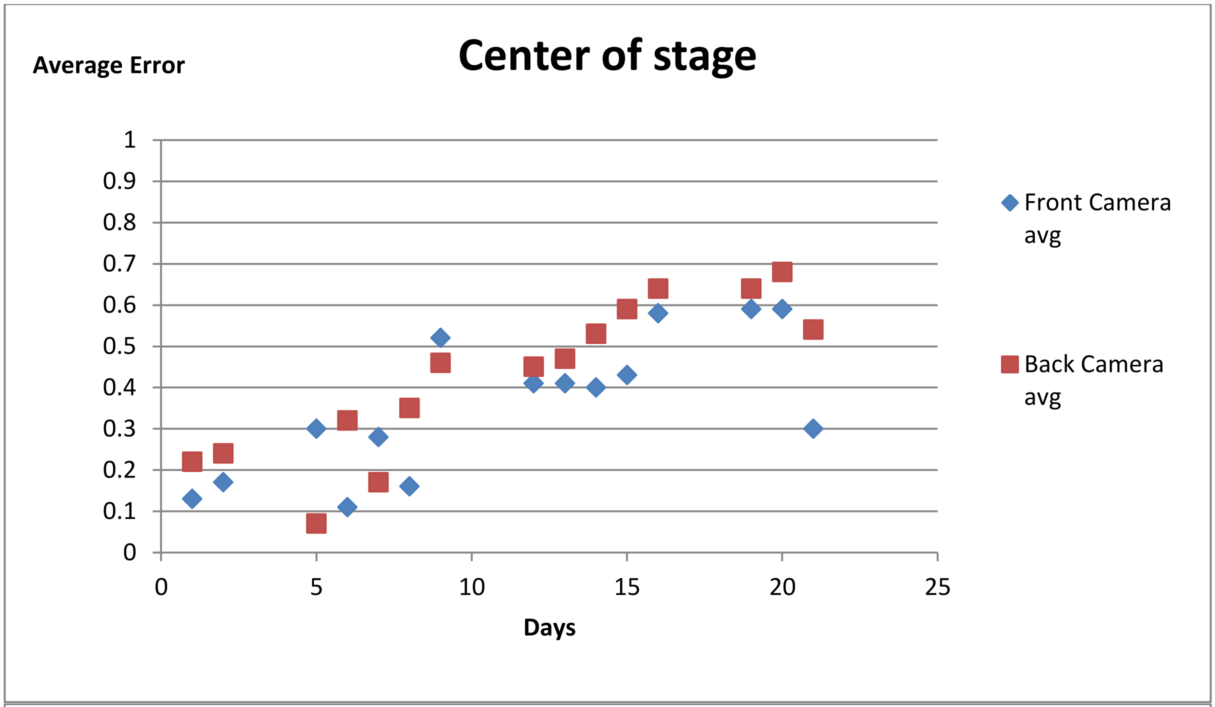
From these experiments it is clear that the geometry of a digitizing probe does play a significant role in the overall accuracy of a motion capture system. More configurations should be tested to try to attain higher levels of accuracy as well as help explain why certain arrangements of markers give better accuracy. These experiments also show that a quality registration is crucial to achieving low errors in multi-camera motion capture systems. More tests should be performed to better understand what methods provide the most accurate registrations as well as how registrations can be preserved so their accuracy does not decay over time.

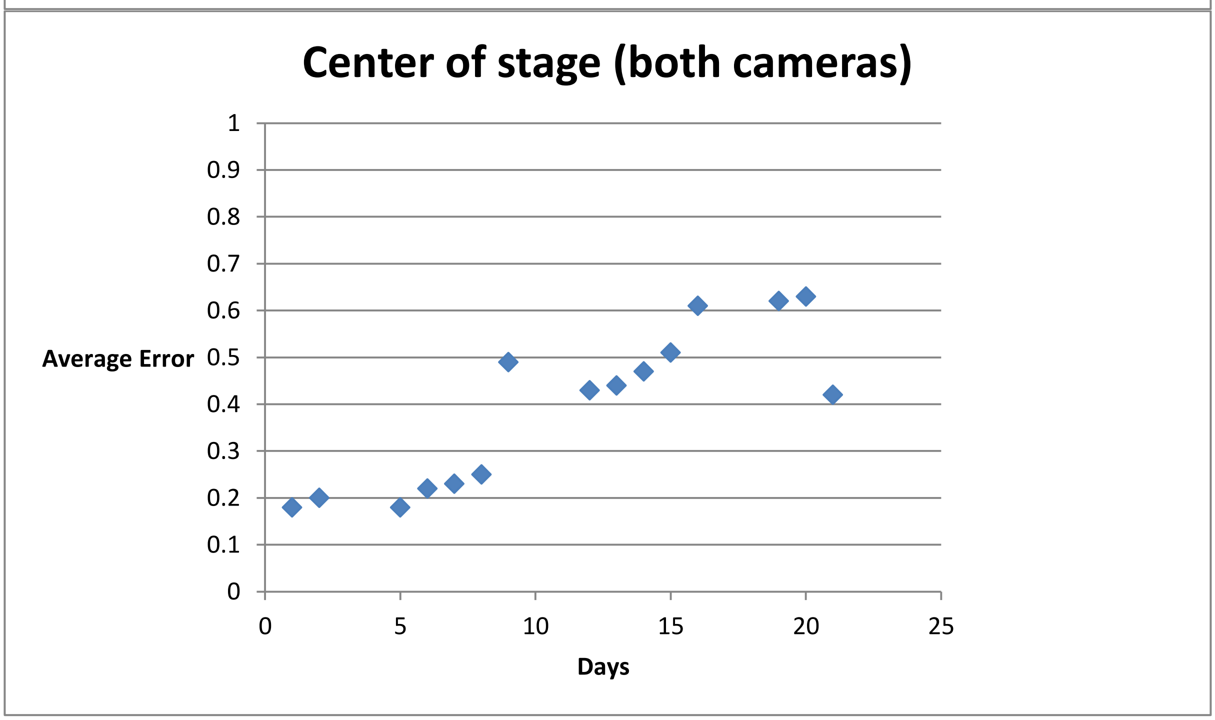
Table 2

Registration	Description	Registration RMS Error	Probe Location	Average Camera Blocking Error
Cube_Reg1	180s throughout volume	0.23 mm	Center of stage	0.19 mm
Sphere_Reg1	60s throughout volume	0.27 mm	Center of stage	0.33 mm
Sphere_Reg2	15s bi-directional through center	.07 mm	Center of stage	0.30 mm
Cross_Reg1	120s bi-directional through center	0.15 mm	Center of stage	0.18 mm
Cross_Reg2	180s throughout volume	0.23 mm	Center of stage	0.20 mm
			Towards front camera	0.11 mm
			Towards back camera	0.14 mm
Cross_Reg3	180s bi-directional through center	0.20 mm	Center of stage	0.12 mm
			Towards front camera	0.45 mm
			Towards back camera	0.24 mm

Table 2: A description of how each registration was performed as well as the accuracy it produced in the camera blocking test. Probe location specifies where the probe was located within the volume of interest when the camera blocking test was performed.

Figure 5


Center of stage
Average Error
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
Days
Front Camera avg
Back Camera avg


Center of stage (both cameras)
Average Error
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
Days