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The paper that I selected is “comparative tracking error analysis of 5 different optical tracking systems, Rasool Khadem ,2000”.Our project name is precise automated kinematic calibration of RCM robots. The main goal of the project is to quantify the error of RCM and develop new and more accurate RCM. One of the most important parts of the project is to determine the precision and the accuracy of Polaris tracking system. And that is the reason why I selected this presentation topic.

Summary

The main topic of this paper is the calibration the precision of the five optical tracking systems (OTS) using jitter methods. In this paper, the Jitter exactly means the standard deviation of the Euclidean distances. And the author tested in x-y-x axis separately. Also, he tested in all range of the each digitizing volume.

Introduction

Generally many position tracking systems are essential part for the clinical use such as surgical tool tracking. And Optical trackers are one of the most popular tool- tracking systems. Optical tracking systems are generally composed of 1D or 2D image sensors and emitters. In other words, it is composed of camera and dynamic reference frame. Five optical tracking systems tested in this paper are listed in the table1.

System	Manufacturer
300 mm Flashpoint	Image Guided Technology Inc. (IGT)
580 mm FlashPoint	Image Guided Technology Inc.
1 m FlashPoint	Image Guided Technology Inc.
Polaris	Northern Digital Inc. (NDI)
Polaris(passive)	Northern Digital Inc.

Table 1.

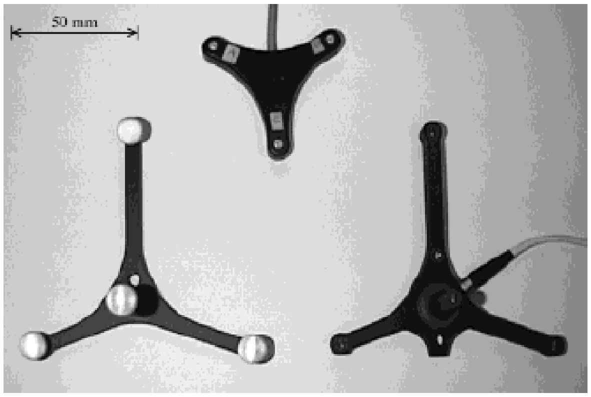


Figure 1. DRF samples

DRF is dynamic reference frame. There are two types of DRF. One is active configuration and the other is passive one. Active configuration emits the light and passive one reflects the light which is emitted from the camera.

Here is the list of DRF use in this paper.

System	DRF
300 mm FlashPoint	3 LED 50 mm ACTIVE
580 mm FlashPoint	3 LED 50 mm ACTIVE
1 m FlashPoint	3 LED 50 mm ACTIVE
Polaris	4 LED Active TRAXTAL
Polaris(passive)	4 LED Passive TRAXTAL

Table 2.

Methods

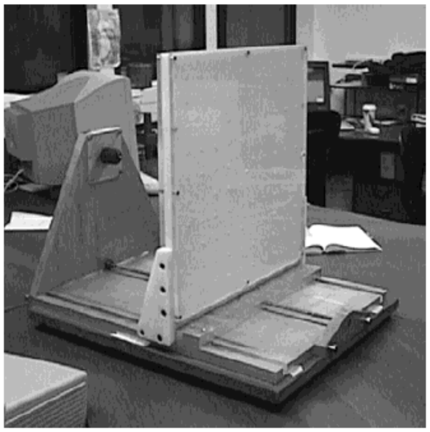
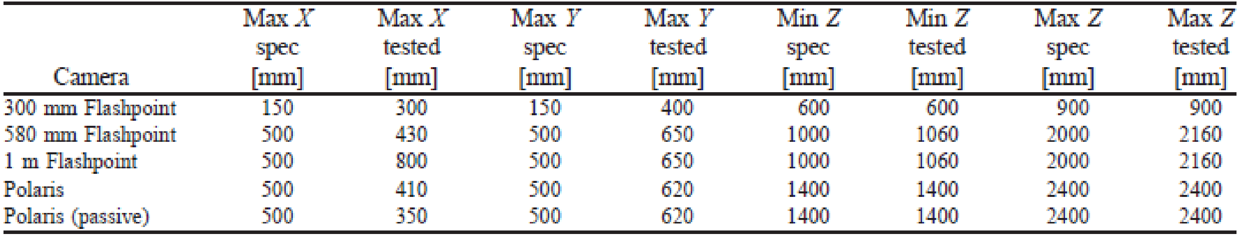


Figure 2. LTA : Linear testing apparatus

The author developed a linear testing apparatus which is called to LTA. The author said LTA is machined precisely. And LTA is consisted of 500 square millimeters plate and there are 100 holes on it. This plates moves in Z direction. The author tried to examine data from all visible range of each OTS. The author tested the range varying the position of the LTA in 3 dimensions. And he selected the smallest possible angle 30 degree for the viewing angle. The spec and tested data are is the table next. It is exciting that the data are pretty different in some part.



Camera	Max X spec [mm]	Max X tested [mm]	Max Y spec [mm]	Max Y tested [mm]	Min Z spec [mm]	Min Z tested [mm]	Max Z spec [mm]	Max Z tested [mm]
300 mm Flashpoint	150	300	150	400	600	600	900	900
580 mm Flashpoint	500	430	500	650	1000	1060	2000	2160
1 m Flashpoint	500	800	500	650	1000	1060	2000	2160
Polaris	500	410	500	620	1400	1400	2400	2400
Polaris (passive)	500	350	500	620	1400	1400	2400	2400

Table 3. Tested and spec digitizing volume

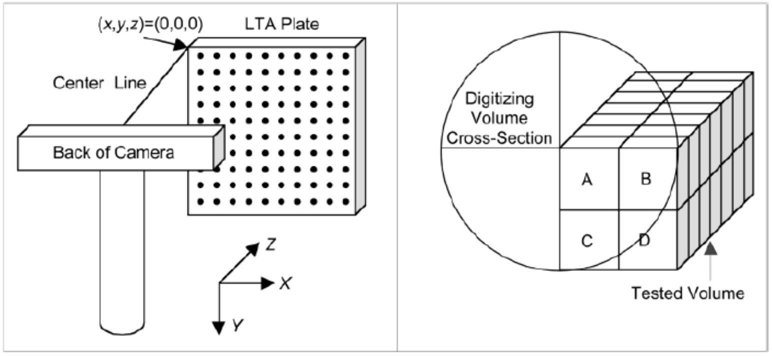


Figure 3. Schematic view of the test

DRF was mounted in the holes on the plate. And the plate was shift 10 cm in z direction. And this process was repeated. The camera was mounted on tripod. And the unbelievable thing is that the orientations of the camera and LTA were perfectly aligned.

$$J_{xyz}=\left\|[X_i\ Y_i\ Z_i]^T-[\mu_X\ \mu_Y\ \mu_Z]^T\right\| \qquad \textbf{(1)}$$

The equation (1) explains the error analysis method,Jitter. X y z coordinates were sampled 100 times at each position and Xi Yi Zi represent them. Using this equation, Jitter measurements were calculated relative to the mean coordinates mu x mu y mu z. And Jx Jy Jz are normalized standard deviation of each axis.

Results

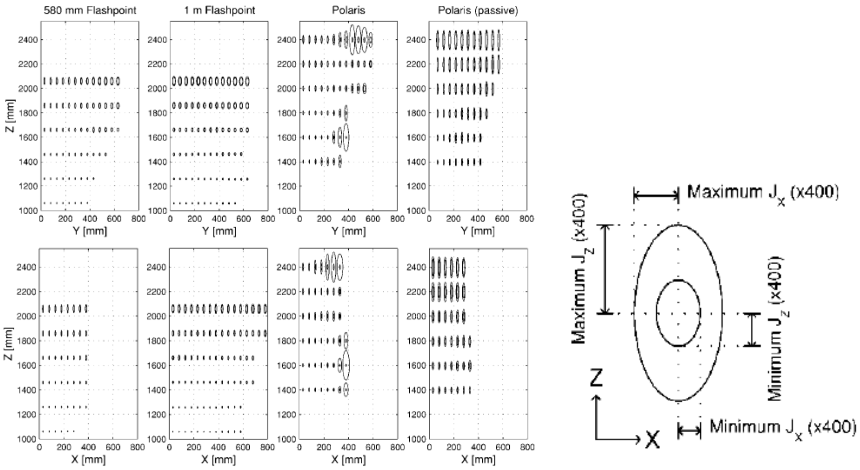


Figure 4. result 1

This figure 4 shows the relative magnitude of the jitter components and how they vary within the volume. Each pair of ellipses in a given plane represents the extremes of the separate components of jitter. The distance along the vertical axis of an ellipse shows the jitter components along the vertical axis. Likewise, the horizontal distance shows the jitter component along the horizontal axis. Inner show the minimum values and the outer shows the maximum values. From the figure 4, result 1 shows that Z-components are dominant compared to X and Y axes.

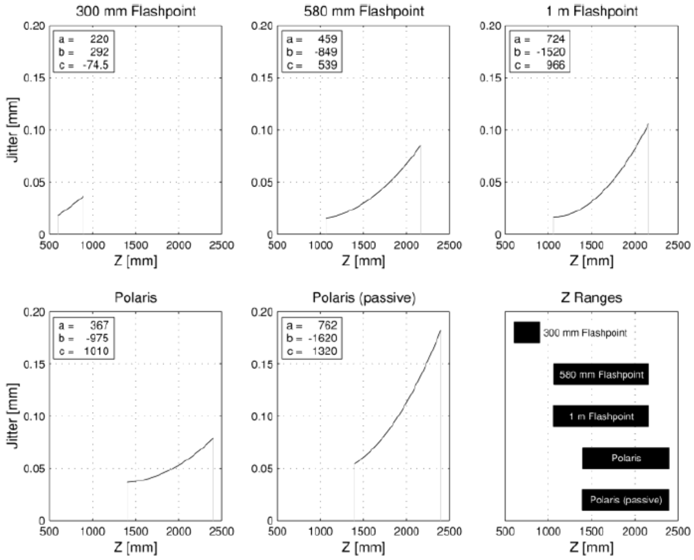


Figure 5.

$$J(z) \approx \frac{az_m^2 + bz_m + c}{10000}$$

(2)

So the author developed a function base on the z-direction component data. Using least square fit, a quadratic model was developed. The equation (2) indicates that how the error in z direction can varies according to the Z distance. Furthermore, the equation (2) can be used for the correction algorithm for the z direction errors.

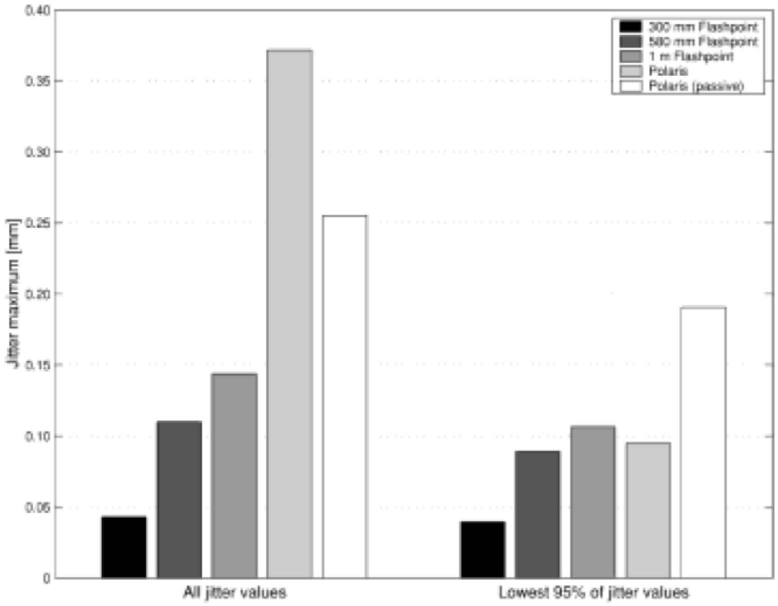


Figure 6.

Figure6 shows the result to compare the five different OTSs. Left graph shows the maximum jitter values for all data. And the right graph is for the lowest 95% data. In the left graph, two Polaris systems show significantly higher error than IGT systems. Also that indicates that IGT systems have much better precision than the NDI Polaris systems. In the right graph, which is for the lowest 95%, all OTSs do not show any significant differences each other. This result shows that for the lowest 95% data, all tracking systems seem to be comparable.

Analysis

In paper, according to the figure 4 results, the figure shows that the jitter values in z-direction shows much worse precision than other 2 X and Y directions. And the author insisted that the x and y jitter components are insignificant compared to the z component, and roughly equal in magnitude. Accordingly, the author suggested that to optimize the precision, OTS should be as close as possible to the surgical field and Z axis of Camera should be in direction that is least clinically significant. The suggestions will allow the camera be rotated to any orientation without any sacrifice in precision. Finally, from the figure 6, it is obvious that IGT systems are better and the active Polaris system shows much higher maximum jitter value than the passive Polaris system.

In my view, there are a few strong aspects of this paper. First of all, the paper tried test 5 OTSs at the same time. There are no relevant papers which dealt with multi kinds of optical tracking systems. Therefore, comparison of different kinds of optical tracking systems seems to be good trial. Secondly, the methods for calibration and analysis in this paper are good. This paper tested and analyzed the error in each x,y,z directions using Jitter method. Also the ellipse method showed the results very clearly. Lastly, this paper tested the digitizing volume and compared with spec data. This information will be helpful for users to determine the location of their apparatus in optical tracking system.

On the other hand, there are also lots of weak points that could have been better. Firstly, the author needed to show more how he could make the two orientations of camera and LTA aligned perfectly. He assumed that the optical tracking systems are perfectly aligned to their apparatus. However, according to my experience in real experiments, it is really hard to make them aligned. The paper should have been shown the methods they used for making them to be aligned or their correction mechanisms to fix the difference. Secondly, the Author did not consider the other static errors such as errors from LTA manufacturing, vibration. In the environment of real experiments, there must be errors caused from their ambient condition such as mechanical vibration. Third, the author only analyzed the precision of OTSs. With only precision data, it is really hard to tell how a system accurate. Therefore, the paper failed to show a perfect error analysis. Moreover, the LTA apparatus can only provide x,y,z axes data. That means the apparatus can not reflect the real case in the clinical use. If the paper tried rotational test or angular test, the results would be more reasonable. Lastly, he developed the quadratic model for Jitter in Z direction and it would be better if he could suggest some correction algorithm.

Future Step

This paper topic is really relevant to our present project. First of all, after we analyze the precision of Polaris system using some statistical method such as jitter, we will develop the new method for the calibration of accuracy. Based on the data, we will develop the mathematical models such as the jitter quadratic model. With the mathematical model, we expect that we can build the error correction algorithm. Lastly, for the apparatus to reflect the typical clinical use, we will consider more than x-y-z movement such as rotational movements or diagonal movements.

Reference

Comparative Tracking Error Analysis of Five Different Optical Tracking Systems, Rasool Khadem,2000

Accuracy assessment and interpretation for optical tracking systems ,Andrew D. Wiles 2004