A CALIBRATION METHOD FOR STEREO FLUOROSCOPIC IMAGING SYSTEMS

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INTRODUCTION

Stereo fluoroscopic motion analysis systems provide the highest precision and accuracy in measuring *in vivo* joint motion. Calibration of these systems is necessary to: 1) correct for the significant image distortion in the image intensifiers; 2) determine the x-ray focus position for each fluoroscopy system relative to its image plane; and 3) determine the spatial relationship between the two fluoroscopy systems.

This study focuses on the determination of the focus position. Previous calibration methods include using the manufacturer's specification of the focus position (Li et al., 2004) and the use of accurately machined calibration boxes with fiducial and control planes (Garling et al., 2005). The accuracy of the manufacturer's specification may be questioned, while calibration data collection with large boxes can be difficult and limiting to the setup. The purpose of this study was to validate a new calibration method which uses a relatively inexpensive fiducial plate and small cube while preserving calibration accuracy.

METHODS

Equipment Two Philips BV Pulsera fluoroscopy systems were used in Digital Exposure mode to collect all images. An acrylic calibration box with 317 fiducial and 21 control markers was built with the control plane distance from the fiducial plane of 400 mm. An aluminum fiducial plate was machined with 406 holes. Both fudicial planes had a squared pattern with 15mm distance between the holes/markers. Lastly, a foam cube with 15 markers was built and average marker positions were determined from RSA recordings with the cube in 3 different orientations. Data analysis was performed using Model-based RSA software (Medis Specials, BV, The Netherlands)

Calibration Three calibration methods were implemented to find the focus positions.

- Method 1: Using the Fiducial-Control plane method (Garling et al., 2005).
- Method 2: Using a fixed position at 1000mm from the image center.
- Method 3: Using a new nested optimization algorithm: the inner optimization loop determined the error of the best match of the foam cube markers given a focus position; the outer optimization loop searched for the focus position that minimized the matching error from the inner optimization loop.

Image distortion was corrected using the fiducial plane markers of the box (Method1) or the fiducial plate (Method2,3). The relative positions of the two fluoroscopy systems were always based on the foam cube data.

Data collection and analysis First, a caliper instrumented with two markers was recorded in three configurations (closed; opened 25.4mm, opened 50.8mm) in three poses each. Second, a box with 16 markers was attached to a micromanipulator which could displace the box along two perpendicular axes with an accuracy of 5µm. Ten displacements of 1mm each were

applied to the box and measured with the fluoroscopic motion analysis system using the 3 calibration methods.

RESULTS

Means and standard deviations (Std 1-3 below) for the 3 caliper configurations were calculated. The difference between the means was compared with the 2 successive 1" (25.4mm) displacements applied to the caliper (Error 1-2 below).

Table 1. Standard deviations (mm) and errors (mm) of measured caliper configurations across the three calibration methods.

	Method1	Method2	Method3
Std1	0.0444	0.0286	0.0243
Std2	0.1893	0.0640	0.0102
Std3	0.0792	0.0463	0.0199
Error 2.5cm	-0.0189	0.0343	0.0252
Error 5.0cm	0.0714	0.0694	0.0837

The mean and standard deviations of the differences between the measured and micromanipulator applied displacements were calculated (i.e., bias and error) as well as of the absolute differences. The root-mean-squared (RMS) error is also presented.

Table 2. Error measures (mm) based on ten micromanipulator displacements across the 3 calibration methods.

	Method1	Method2	Method3
Mean	-0.0086	0.0030	0.0002
Std	0.0178	0.0185	0.0153
Mean (abs)	0.0150	0.0125	0.0098
Std (abs)	0.0123	0.0133	0.0113
RMS	0.0190	0.0178	0.0145

DISCUSSION

The caliper results show that the new calibration method (Method3) had the highest and most consistent precision (lowest std) of 18.1µm (average of the 3 measures). The micro-manipulator results show that the new calibration method has the lowest bias (0.2 µm) and highest accuracy (15.3 µm) as well as the lowest RMS error of 14.5 µm.

Simply assigning the focus position to the manufacturer's specification (Method2) also provided good results. Precision is 2.6 times less (46.3 µm) compared to new calibration method, but the accuracy is only 21% less while the bias is limited to 3 µm.

The Fiducial-Control plane method (Method1) demonstrated the poorest results in the experiments with reduced precision and increased bias. The accuracy was similar compared to the other methods.

The primary limitation of this study was that the acrylic calibration box was not manufactured with the same tolerance as the fiducial plate. We hypothesize that the resulting reduced accuracy of the distortion correction in Method1 caused the reduced calibration performance rather than the focus position determination. A second limitation of this study is that the Direct Linear Transform (DLT) method was not included (You et al., 2001).

CONCLUSION

The new calibration method is equal to or better than the two currently reported calibration methods that were tested.

REFERENCES

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